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AN INVESTIGATION OF THE SQUADRON AIR COMBAT TRAINING SYSTEM (HAVE ACME)

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JUNE 1996

FINAL REPORT

Approved for public release; distribution is unlimited.

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
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14. ABSTRACT
The cost and limited location of air combat maneuvering instrumentation (ACMI) ranges make aerial combat training with accurate postflight reconstruction tools an expensive and infrequent opportunity. The Squadron Air Combat Training System (SACTS) was designed to capitalize on portable, lightweight Global Positioning System (GPS) equipment using the commercially available coarse acquisition code to provide fighter training squadrons with a low cost, limited ACMI capability. The device was carried into the cockpit where a time history of aircraft position was recorded and, after postprocessing, the flight was viewed in a three-dimensional playback tool running on a laptop computer. The test program was designed to evaluate the suitability of the SACTS for use in a USAF fighter squadron training environment. Eighteen sorties totaling 20.8 hours were flown from 4 April to 1 May 1996 at the Air Force Flight test Center, Edwards AFB, California. Testing was conducted by the Test Pilot School Class 95B.

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PREFACE

This report contains the results of a concept feasibility demonstration of the Squadron Air Combat Training System (SACTS). The portable system was designed to capitalize on the global positioning system (GPS), commercially available, coarse acquisition code to record a time history of the aircraft's position during air combat maneuvers. Postprocessing of the GPS position information from all aircraft in the engagement provided a three-dimensional visualization of the maneuvers which could be used for fighter squadron training.

The SACTS was developed by BEACON and UHL Research Associates, Inc., and was tested by the USAF Test Pilot School under a Cooperative Research and Development Agreement with the Air Force Flight Test Center at Edwards AFB, California (Reference 1). Testing was conducted by students of Test Pilot School Class 95B from 9 January to 1 May 1996 as part of the Test Management Phase Curriculum under job order numbers (JONs) M96J0200 and CR960100.

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EXECUTIVE SUMMARY

This report contains the results of a concept feasibility demonstration of the Squadron Air Combat Training System (SACTS). This portable system was designed to capitalize on the global positioning system (GPS), commercially available, coarse acquisition code to record a time history of the aircraft's position during air combat maneuvers (ACM). Postprocessing of the GPS position information provided not only aircraft position but also traditional aerodynamic parameters such as bank angle, load factor, pitch angle, angle of attack, and calibrated airspeed. By combining GPS information from all aircraft in the engagement, the SACTS software provided a three-dimensional visualization of the aerial combat which could be used for fighter squadron training. Given these capabilities, the system could be used for air combat training independent of geographically limited and expensive air combat maneuvering instrumentation ranges.

Testing was performed from 9 January to 1 May 1996 as part of the Test Management Phase of the USAF Test Pilot School curriculum. Eighteen sorties totaling 20.8 hours were flown from 4 April to 1 May 1996 at the Air Force Flight Test Center (AFFTC), Edwards AFB, California. A combination of AFFTC T-38, F-15, and F-16 aircraft were used to conduct the evaluation.

The overall test objective was to evaluate the suitability of the SACTS for use in a USAF fighter squadron training environment. Emphasis was on the ability of the system to accurately reconstruct the aircraft's flightpath during a variety of typical ACMs. Both within and beyond visual range engagements were tested. The software and hardware used during the test program were prototypes for the demonstration of the concept only and were not considered representative of a final system configuration.

All test objectives were met. Overall, the SACTS concept held promise, but the current prototype hardware performance was unsatisfactory for immediate use in a USAF fighter squadron training environment. The postprocessing software provided a satisfactory reconstruction of the flightpath and acceptable aerodynamic parameters given an accurate GPS position solution. The visualization program provided the pilot with a simple and useful tool to debrief air combat engagements. The deficiency in the prototype hardware was its inability to maintain a GPS position fix during aggressive vertical maneuvering. The data suggested that this weakness may have been the result of a combination of GPS inaccuracies in the vertical axis and constellation blanking during these types of maneuvers. The primary recommendations were to improve the capability of the GPS receiver to provide accurate position data through operationally representative ACM and to reduce the processing time so the playback could be available shortly after the flight. Another recommendation underscored the importance of adding the capability to account for winds during within visual range engagements. The SACTS hardware was found to be incompatible with operationally representative F-16 aircraft. The detailed results were classified.

While the software provided a significant capability and useful tool at the squadron level, some modifications in the process and display of the engagements were considered necessary before it could be deemed satisfactory for use in the training environment. A list of recommendations were made to ensure the suitability and to enhance the operability of the SACTS software.

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INTRODUCTION

GENERAL

This report presents an evaluation of the Squadron Air Combat Training System (SACTS). The purpose of the HAVE ACME test program was to conduct a concept feasibility demonstration of a portable global positioning system (GPS) receiver and its associated software as a debriefing tool for a fighter squadron's air combat training (ACT) missions.

This test program was a joint effort between the Air Force Flight Test Center (AFFTC) and BEACON, a commercial entity, under a Cooperative Research and Development Agreement (CRDA), Reference 1. Testing consisted of 18 sorties, flown in a combination of T-38, F-15B, and F-16B aircraft. A total of 20.8 flight hours were flown from 4 April to 1 May 1996. These test flights were conducted by Class 95B of the USAF Test Pilot School (TPS) as part of the Test Management Phase Curriculum.

BACKGROUND

Reconstruction of air combat engagements in the training environment was a daunting task when faced with multiple-on-multiple aircraft engagements. The USAF invested considerable resources developing air combat maneuvering instrumentation (ACMI) ranges at only a few locations throughout the world. The cost and scheduling constraints of such a resource meant that the average pilot made only a limited number of visits to an ACMI range. While the fully instrumented ranges provided a wealth of valuable and accurate engagement environments and data collection, the resource could not be used at a frequency that operational units would prefer. The SACTS was designed to make use of the availability of miniature GPS receivers (commercially available coarse acquisition code) and data recorders with the potential of bringing a low cost, limited ACMI capability into each operational squadron.

A self-contained receiver/recorder unit and GPS receiving antenna were carried to each cockpit during this test program. Two single-ship and eight two-ship missions were flown. Once back on the ground, each data recorder was downloaded into a 75-megahertz Pentium processor driven laptop computer. The SACTS software then read the downloaded information and recreated the engagements in a three-dimensional (3D) playback which provided the operator with several options for perspective including God's-eye and in-cockpit views. Weapons employment information was manually entered into the playback routine.

TEST ITEM DESCRIPTION

Successful operation of the SACTS required two elements: an airborne and ground element. The airborne element received and processed GPS signals to yield a position solution which was recorded in flight. This portable hardware consisted of a GPS receiver/recorder unit, power supply, receiving antenna, associated antenna cable, and a test only display unit. The ground element was the postprocessing and visualization software.

Since the test purpose was that of concept demonstration, the test item was not considered production representative in form or fit but provided representative performance that could be assessed for future products.

SACTS Hardware:

The receiver/recorder was a Model 25 GPS navigator and secure flight recorder made by Cambridge Aero Instruments, featuring Version 4 firmware. It housed a Garmin-25 PhaseTrac 12™ 12-channel parallel GPS receiver engine using the coarse acquisition (C/A)-code GPS signal to record position solutions at 1 hertz. The Garmin receiver was designed to operate and maintain continuous position tracking through maneuvers at elevated load factors of up to 6 g's. Operation of the receiver/recorder is described in References 2 and 3. Connected to the receiver/recorder was a small handheld liquid crystal display (LCD) that provided information on the status of the received GPS constellation, and on the quality of the signals. Although not a part of the article under test, the display was used to collect supporting data for diagnostic use. A detailed description of the receiver/recorder and display units can be found in Tables A1 and A2. All hardware elements used in the test program are shown in Figure A1. A detailed description of the Garmin-25 PhaseTrac 12™ GPS software engine can be found in Table A3.

The power supply was a rechargeable nickel cadmium battery which provided 500 milliampere-hours at 12 volts. The power supply package was 5.6 inches long, 2.1 inches wide, and 0.7 inch tall with a weight of 0.55 pound. This package consisted of ten 1.2-volt batteries, connected in series.

Three GPS receiving antennas were evaluated during this test program. The antenna cables were flight-worthy coaxial type. An antenna cable description is shown in Table A4. The antenna were as follows:

1. An active round hemispherical antenna: Rockwell Collins portable lightweight GPS receiver (PLGR) number 013-1925-030. A detailed description can be found in Table A5 and Figure A2.

2. An active helical stick antenna, provided by Garmin, in which the received signal was biased by 5.0 volts.

3. A passive round hemispherical antenna, made by Matsushita Electric Works, part number PU 21522 GPS, also provided by Garmin.

There were three options evaluated for configuring the SACTS equipment in the cockpit. These options are included in Table 1. The hardware was installed or worn in the rear cockpit. All hardware was installed in a modified survival vest for configurations 1 and 2. This vest modification was designed by AFFTC life support personnel and is shown in Figure A4. Configuration 3 required a Class II Modification for temporary installation of equipment. This was approved for installation in a T-38 by Class II Modification number M96A135A.

SACTS Software:

The ground element of the system consisted of the postflight processor (PFP) and the air combat visualization analysis tool (ACVAT) Version 1.0. The software was hosted on a 75-megahertz Pentium processor driven laptop computer. The software was proprietary and required a key in the form of a coded small computer systems interface (SCSI) plug to operate. The input to the postflight processor was the GPS 3D position solution at 1-second intervals. Algorithms in the software used the information to estimate aircraft attitude parameters, angle of attack, load factor, and other variables that could then be plotted or visualized in the 3D visualization routine, ACVAT. A brief description of the variables used in the PFP are provided in Appendix F. Software description and operator instructions for the playback tool are contained in the ACVAT user's guide in Reference 4.

Test Aircraft:

Three AFFTC T-38A aircraft, USAF S/Ns 68-8135, 68-8154, and 68-8205, were flown in the evaluation. These aircraft were two-place supersonic jet trainers built by Northrop Corporation. The canopy of the rear cockpit was flush with the aircraft's fuselage, resulting in a restricted rearward field of view (FOV). The T-38A flight manual (Reference 5) provides a detailed description of the T-38A. To aid in data collection, the installed metraplex data acquisition system (DAS) was used. The DAS resolutions and accuracies can be found in Table E1.

Two AFFTC F-15B aircraft, USAF S/Ns 76-0130 and 76-0134, were flown in the test program. They were two-place supersonic air superiority fighters built by McDonnell Douglas Aerospace. The conventional hydraulic flight controls were supplemented with an electronically controlled control augmentation system (CAS). The aircraft had an APG-63 air-to-air radar. The F-15B featured a bubble canopy with a central canopy bow. The F-15B flight manual (Reference 6) provides a detailed description of the

Table 1
SACTS EQUIPMENT CONFIGURATION

Configuration	Receiver Location	Antenna Type	Antenna Location	Figure
1	Survival Vest	Active Hemispherical	Helmet	Figures A3 through A7
2	Survival Vest	Active Stick	Survival Vest	N/A
3	Map/Pin Case	Passive Hemispherical	Glare Shield	Figure A8

Note: N/A - not applicable

aircraft. This aircraft also contained special instrumentation (SI) in the form of an airborne test instrumentation system (ATIS) for data and video collection. The ATIS resolutions and accuracies can be found in Table E2.

Two AFFTC F-16B aircraft, USAF S/Ns 78-0081 and 78-0098, were flown. The F-16B was a two-place supersonic multirole fighter built by Lockheed-Martin Corporation. The aircraft used a redundant electronic fly-by-wire flight control system. The aircraft had an APG-66 radar, and a single piece bubble canopy. The F-16B flight manual (Reference 7) provides a detailed description of the aircraft. The aircraft flown during the program had a production ¾-inch video recorder.

TEST OBJECTIVES

The overall objective for this flight test program was to evaluate the suitability of SACTS for use in a USAF fighter squadron training environment.

Specific test objectives were to:

1. Evaluate the capability of the SACTS to create and display an adequate flightpath history of typical air combat maneuvers (ACM).

2. Evaluate the accuracy of the SACTS for beyond visual range (BVR) engagements.

3. Evaluate the accuracy of the SACTS for within visual range (WVR) engagements.

4. Evaluate the operability of the ACVAT.

5. Evaluate the usability of the manual insertion of weapon employment information in ACVAT.

All test objectives were met.

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TEST AND EVALUATION

TEST METHODS AND CONDITIONS

Both ground and flight testing were conducted. Ground tests were designed to ensure that the SACTS equipment would operate in the cockpit environment and to determine an effective antenna configuration for flight testing. No attempt was made to optimize the location of the antenna in each cockpit. Ground testing consisted of operating the SACTS equipment in the closed cockpit with systems and engine(s) operating. The LCD was used to determine the number of satellites tracked by the receiver and their signal strengths. The aircraft was rotated through several headings during the testing. Systems were monitored and, where available, system built-in-tests (BIT) were accomplished to ensure no electromagnetic compatibility issues were uncovered.

Flight testing was divided into four phases. A complete list of missions flown is provided in Appendix D, Table D1. Phase I testing evaluated the effects of fuselage blanking on the ability of the GPS to provide accurate position information using a cockpit mounted antenna. Phase I testing also evaluated the ability of the GPS to reacquire a 3D position fix if it was lost due to maneuvering. For all tests a minimum of six satellites tracked and a 3D position fix was required prior to maneuvering. The test aircraft was then placed in the attitudes shown in Table D2 and held for 5 to 10 seconds. The number of satellites being tracked were observed for each maneuver. The ability of the GPS receiver to reacquire a position fix in flight was evaluated by disconnecting the antenna until No Fix was displayed on the GPS display. The aircraft heading, velocity and/or altitude was then changed (Table D3). The antenna were then reconnected to determine the time required to regain a 3D position fix.

Phase II testing evaluated the accuracy of the SACTS system during operationally representative maneuvers (loops, level turns, post holes, etc.). The SACTS processed time histories of airspeed, load factor, bank angle, and pitch and were compared with the aircraft DAS data for accuracy. Time histories were correlated using universal coordinated time (UTC) as a reference. See Table D4 for a list of maneuvers flown. The DAS resolutions and accuracies can be found in Appendix E.

Phase III testing was used to evaluate the range and relative altitude accuracy of the SACTS system. The absolute position and altitude were not considered important for this system's intended use. Relative range and relative altitude were the only critical parameters. For this testing, the F-15 and F-16 onboard radars were used as the truth source for range information. Accuracy of cockpit displayed radar range information was limited by the head-up display (HUD) and not radar accuracy. For the F-15, range could be accurately read within ±200 feet for ranges inside 12,000 feet and ±600 feet for longer ranges. For the F-16, range was accurate to ±100 feet inside of the 6,000 feet range and ±600 feet at longer distances. This accuracy was considered sufficient for determining the suitability of this system for its intended use. For relative altitude comparison, the aircraft altimeters were matched at 350 knots and 15,000 feet. The altitude difference read from the cockpit altimeters was then used in determining a relative truth source. Altitudes were held within 100 feet during the relative altitude testing resulting in a ±200 feet accuracy. The maneuvers in Table D5 were flown using both the F-15 and F-16 with T-38 aircraft as targets.

Phase IV testing was an evaluation of the ACVAT software for usability. Tactical formation, advanced rejoins and BVR intercepts were flown. Simulated missile shots were taken on the advanced rejoins and BVR intercepts to evaluate that portion of the SACTS software. (See Figures D1 through D5 for a description of the maneuvers flown.) Aircrew comments were recorded throughout the test period. Each aircrew member also completed a project developed questionnaire. The questionnaire is included in Appendix C with the recorded comments and ratings. The final flight test mission was a top-to-bottom review of the SACTS system. During this mission, an experienced F-15E pilot, unfamiliar with the SACTS system, performed the BVR intercepts and advanced rejoins in an F-15B against a T-38A target. The pilot then debriefed the mission using the SACTS software presentation and provided comments about the usability of the entire system in an operationally representative environment. The evaluation pilot did not wear the modified vest or download/convert the data for use with the ACVAT software. These actions were not considered representative of the hardware and software that would eventually be used operationally and were, therefore, carried out by members of the project test team.

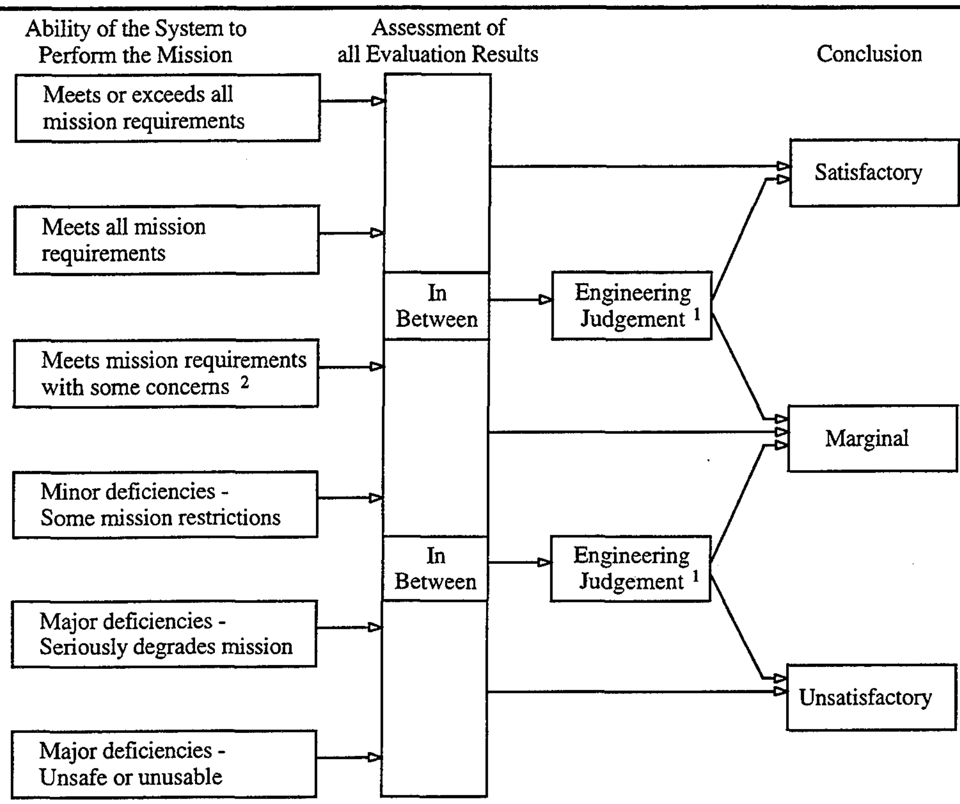
All SACTS results were processed using a laptop computer with a 75-megahertz Pentium processor. The overall suitability of the system was evaluated using the standard AFFTC descriptor evaluation scale provided in Figure 1.

TEST RESULTS AND ANALYSES

Test results were focused in three areas, each of which supported a number of objectives. First, the GPS receiving equipment had to acquire and maintain a position fix through ACM in order to provide the postprocessing software with the raw data needed to generate a postflight reconstruction. Second, the postflight reconstruction had to generate aerodynamic information with enough accuracy to be useful when displayed. Finally, the visualization routine needed to provide the aircrew with an easy to use, value added tool for mission debriefing.

Maintaining GPS Position Fix:

Ground tests with the three candidate antenna in three separate cockpit locations provided clear indication that the active Rockwell PLGR antenna mounted on the helmet of the rear cockpit aircrew member provided unobstructed viewing to more satellites than any other antenna option. The active stick antenna mounted in the survival vest consistently maintained track of three to four fewer satellites than the helmet-mounted antenna and two to three fewer satellites than the glareshield-mounted antenna. The best two options (helmet and glareshield) were flown during initial flight testing with roughly equivalent



[1] - Results which lie between Marginal and Satisfactory or Unsatisfactory may require engineering judgement to determine if the system was Satisfactory, Marginal, or Unsatisfactory.

[2] - For this mission impact, enhancements may be desired, but improvements are not required.

Figure 1 AFFTC Descriptor Evaluation Scale results. The cumbersome installation of the glareshield antenna in the T-38 and safety concerns with a glareshield antenna in the F-15 and F-16 led to the selection of the PLGR mounted on the helmet as the antenna configuration of choice for the remainder of the test program. Although the detailed results were classified, the SACTS hardware was found to be incompatible with operationally representative F-16 aircraft during ground testing.

During flight test, the estimated horizontal and vertical GPS position errors were recorded for postflight review. As the GPS position fix degraded from 3D to two-dimensional (2D), the vertical position error value was automatically set to zero. A complete loss of fix resulted in the horizontal position error also being set to zero. Plots of the estimated position errors for horizontal and vertical maneuvers are shown in Figures B1 through B4. Figures B1 and B2 represent a series of 4-g, 90-degree level turns. Although position error increased slightly during maneuvering, a 3D position fix was always maintained. Figures B3 and B4 represent the system's behavior during a clover leaf maneuver and were comparable to all of the operationally representative steep vertical maneuvers performed. These figures show that the system had difficulty maintaining position fix while maneuvering in the vertical.

The behavior of the raw GPS altitude position estimate could be monitored using the handheld display during flight, but was not available in the SACTS data stream after postprocessing. Qualitatively, the behavior of the altitude during rapid climbs or descents was a 2,000- to 3,000-foot lag. If the climb was followed by an inverted pullout to level flight, the GPS altitude would catch up and then continue to increase (decrease during dives) until stabilizing at some new altitude which was, at times, up to 40,000 feet in error. The receiver would spend several seconds reporting the same incorrect altitude until dropping to a 2D fix. A subsequent drop to no position fix usually quickly followed. At times, the 2D fix was maintained for 30 to 60 seconds. If the receiver did not regain 3D position fix within 60 seconds, power was removed from the unit. After a power reset, a 3D position fix was acquired in 10 to 20 seconds. Figure B5 shows the altitude behavior during the clover leaf maneuver. Again, this behavior was representative of results for all operationally representative maneuvers in the vertical axis. The barometric altitude from the aircraft's instrumentation system could be seen peaking at approximately 19,000 feet pressure altitude and then beginning the descent. The GPS altitude ran off at that point and continued to 36,000 feet where it dropped lock both in the vertical and horizontal position.

Figure B6 shows the complete database of a variety of operationally representative maneuvers flown during the flight test program. Aggressive vertical maneuvers (Immelman, Split-S, Post Hole, Notch, and Clover Leaf) resulted in a loss of 3D position fix more than 50 percent of the time compared to less than 10 percent during maneuvers in the horizontal plane. Flying a vertical maneuver heads-up (i.e., Roller Coaster) did not lead to fix loss.

The accuracy of C/A code GPS in the vertical axis was less accurate than the position determination in the x-y plane (References 8 and 9). These inherent inaccuracies, coupled with constellation masking during the attitudes associated with vertical maneuvers, were likely the cause of the inability to maintain 3D fix during vertical maneuvering. The use of the military encrypted, higher accuracy P-code GPS signal would reduce the inherent error in the GPS derived position solution. The software implementation of the tracking loops in the GPS engine may also have affected the tracking ability during these maneuvers. **The ability of the GPS receiver to maintain position tracking through operationally representative maneuvers should be improved. (R1)**[1]

Postflight Reconstruction:

Given a time history of GPS position, the task of recreating the entire flightpath and attitude history of the aircraft fell to the SACTS postprocessing software. Figures B7 through B10 show the data derived by the SACTS software as compared to the onboard data system for the same series of 4-g, 90-degree level turns as referenced in the previous section. These data were representative of the results collected throughout the flight test program. Even though there were short periods of inaccuracies, the overall performance was considered satisfactory for training purposes. When the GPS position data were inaccurate or dropped to a 2D fix, the postprocessing was not able to adequately smooth the solution. Figures B11 through B14 show the same parameters reconstructed from a combination of vertical notches and oblique turns. Aircraft barometric altitude from the data acquisition system was also shown to illustrate the correspondence of altitude inaccuracies with vertical maneuvering. Although less

[1] Numerals preceded by an R within parentheses at the end of a paragraph correspond to the recommendation numbers tabulated in the Conclusions and Recommendations section of this report.

aggressive vertical maneuvers such as the oblique turns were tracked relatively well, the flightpath reconstruction during aggressive vertical maneuvers was unsatisfactory for the training role.

Since the software made the assumption that all accelerations applied to the flightpath were the result of coordinated maneuvers, the software did not model uncoordinated flight. Figures B15 and B16 show the bank angle and load factor, respectively, during a set of three, slow aileron rolls. Since the majority of an air combat engagement was flown in coordinated flight, this was not considered to have had a significant impact for the intended role.

Some inaccuracies in aerodynamic parameters were observed and unavoidable with a system that uses groundspeed and direction along with an atmospheric model for heading and calibrated airspeed determination. In the SACTS system, winds were assumed zero. From vector mathematics, a 30-knot error in crosswind resulted in a 5.7-degree heading and an aspect error for an aircraft traveling at 300 knots. Winds of 100 knots were not uncommon and resulted in an 18.4-degree error. The zero wind assumption affect on airspeed (Figure B17) shows velocity during a series of 2- 3-, and 4-g's, 360- degree turns in a 25-knot northerly wind. The SACTS computed velocity was seen oscillating about the actual velocity as the aircraft transitioned from headwind to tailwind. These deficiencies had a significant affect on reconstructing an accurate representation of close-in air combat maneuvering and, consequently, verifying aircraft relative nose position and shot parameters. The current system, therefore, was unsatisfactory for use as a debriefing tool for basic fighter maneuvering missions. **The system should be provided with a simple method to account for wind effects on the trajectory reconstruction. (R2)**

Airspeed and angle-of-attack (AOA) calculations also assume a standard atmosphere and simplified aircraft model. Errors due to these assumptions, however, were small and did not affect the suitability of the system. Bank angle and load factor were not significantly affected by these assumptions as shown in Figures B18 and B19.

Adding a second (or multiple) aircraft into the engagement required accurate relative position information for useful training purposes. Figures B20 and B21 show the correlation between the range calculated by SACTS using input from the two GPS receivers and the range determined by air-to-air radars on the F-15 and F-16 for both BVR and WVR intercepts. Figure B22 shows the altitude separation during three engagements. The SACTS system was able to provide correlation within the accuracies which were considered satisfactory for use as a training tool.

Software Usability:

The ability of the software to provide the user with an easy to use and clear visual tool to debrief the mission was assessed independently of the system's capability to accurately reconstruct the flightpath. Data were collected in the form of completed questionnaires as shown in Appendix C and test team comments throughout the program. The ratings and comments on the software capability, effectiveness, and friendliness of use were clearly consistent between all evaluators. The sample of users evaluating the system consisted of the project test team and one evaluation pilot who flew the final graduation exercise mission. Comments, therefore, reflected operators with a mix of experience on the system.

All evaluators considered the system satisfactory in its ability to reconstruct and display BVR engagements but unanimously unsatisfactory in WVR engagements. Overall, the software structure and commands were rated quite friendly and straightforward with the easy quick reference checklist from the user's manual (Reference 4) which was considered very handy and effective. The deficiencies are discussed in this section with recommendations for resolution where appropriate. The recommendations in the software evaluation took two forms; those deemed mandatory to make the software suitable for use in the training environment, and those deemed desired but not mandatory to improve user friendliness and operability.

To help visualize the basis of the recommendations, samples of the computer graphic display setups of a WVR engagement and subsequent stern conversion of a red aircraft towards a cooperative blue target are presented in Figures 2 through 4. All three pictures are representations of the same scenario from three different perspectives taken at the same instant. Figure 2 is a 3D representation of the intercept taken from a random azimuth and tilt (gridlines are oriented along the cardinal headings, North-South, West-East). Figure 3 is a God's-eye view;

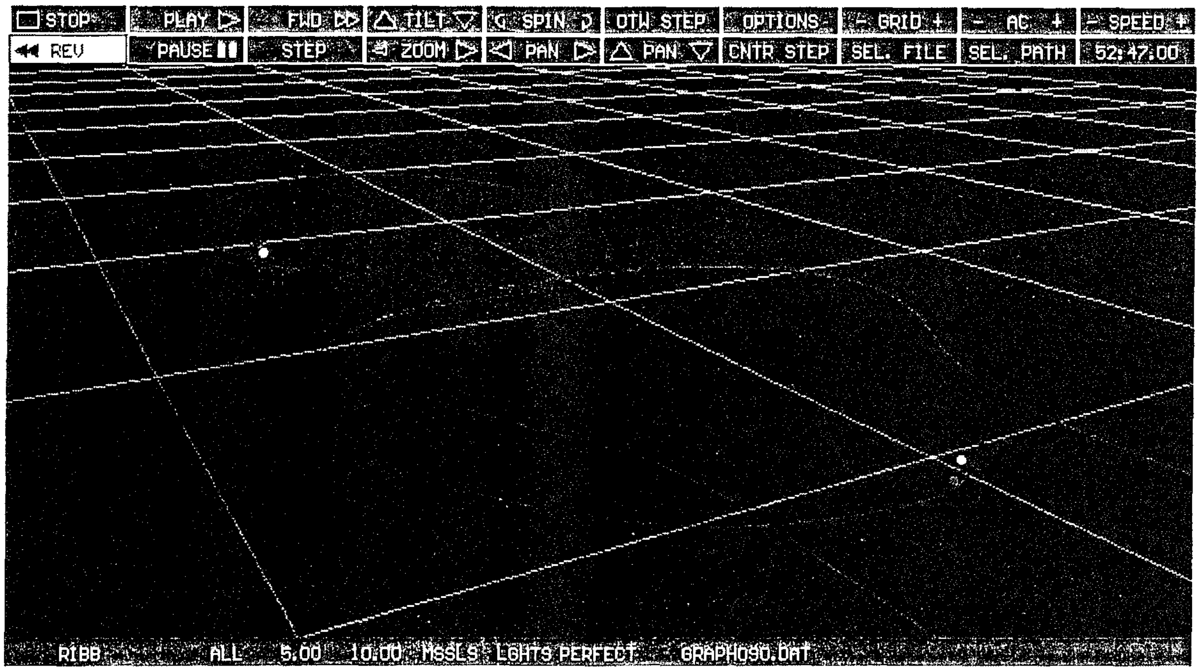


Figure 2 Three-Dimensional Representation of Intercept From WVR Setup

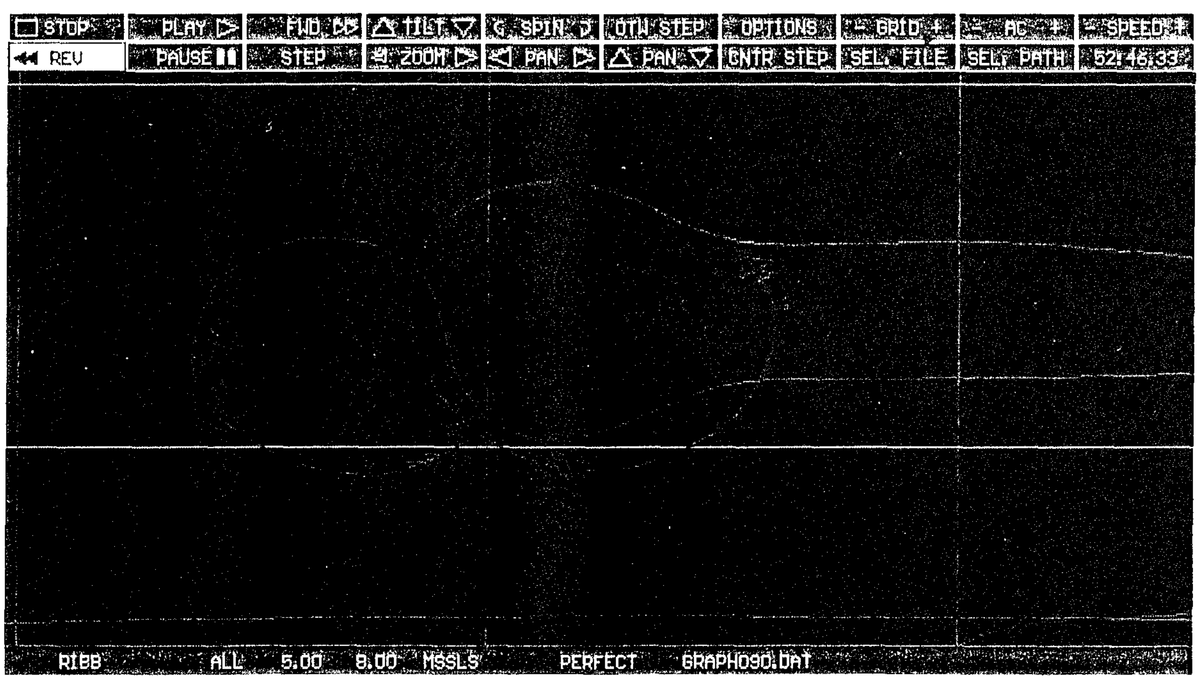


Figure 3 God's-Eye View of Intercept From WVR Setup

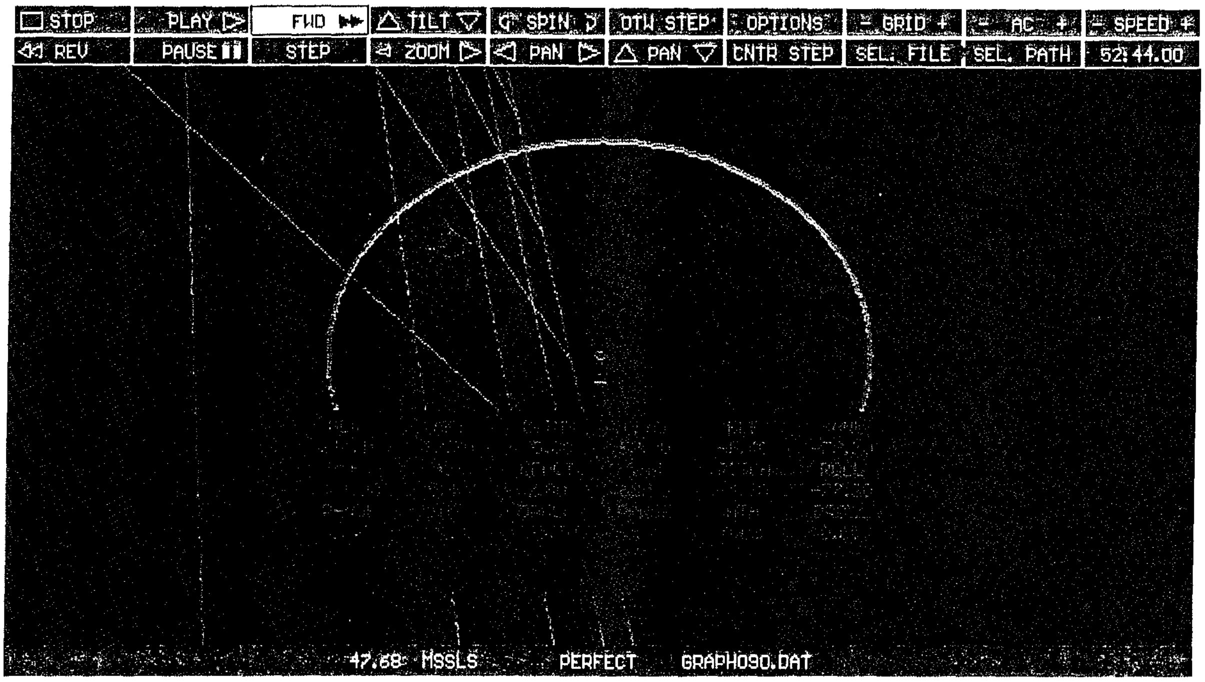


Figure 4 Cockpit View From Red Fighter

the size of the gridline (5 nautical miles in this case) gives a quick estimate of the range between the two aircraft. The precise range, together with aerodynamic parameters (angle of attack, calibrated airspeed, altitude, load factor, etc.) are available in the red cockpit view in Figure 4. In all three, the mouse-driven function selection is clearly displayed at the top of the screen, and an information bar displaying some of the current setup options on the bottom.

Processing time was evaluated to ensure a postmission debrief would begin in a timely fashion. Using two aircraft and the software run variables given in Appendix F, the software running on a 75-megahertz Pentium processor required 35 minutes for a 1.2-hour mission. Processing time was a direct function of the number of aircraft in the engagement and, therefore, a four-ship mission would be expected to take over 1 hour to process. These time requirements were considered unsatisfactory for an operational environment where, at present, mission debriefs would be held as soon as possible and typically within 20 to 30 minutes of the flight. The added benefit of the SACTS debriefing tool would be worth a slight additional delay. **Processing time should be reduced such that debriefs would begin in less than approximately 40 minutes for typical 1 hour, 4 versus 4 engagements. (R3)**

In addition, if missile flyout capability were desired, the processing would not begin until the shot time and target of the shot were identified by review of HUD tapes. In a multiple ship environment, the ability to identify the target would require processing and reviewing the mission through SACTS without missile shots and then reprocessing the mission once the target aircraft could be identified. This additional processing of the engagement, coupled with the difficulty of implementing accurate missile flyout models, made the manual insertion of weapon employment information of limited value. **The manual insertion of weapon employment information should not be pursued. (R4)**

During air combat maneuvers (ACM) mission debrief it was important to understand relative kinematics between two aircraft. Lack of closure velocity (V_c), range, and aspect angle information computed only for target aircraft within ±45 degrees of the aircraft's nose seemed to place unnecessary limitations on the system's capability. **Closure velocity, range, and antenna train angle information should be provided for the two aircraft closest in range and, by selection, between any two aircraft in the engagement. (R5)**

The playback commands (STOP, PLAY, FWD, REV, PAUSE, STEP) appeared to mimic controls of standard videocassette recorders (VCR). The controls, however, were not functionally equivalent to a VCR which led to many user errors and much confusion. ***Basic playback commands should be modified to mimic standard VCR equipment operation. (R6)***

The analog control of tilt angle and azimuth POV when in the God's-eye view was considered valuable. A reset command existed to return the system to a view with no pan or tilt (directly above the engagement). The availability of a similar reset for a vertical view would make it easier for the users to reacquire a standard, familiar view of the flight. A quick reset option of real-time playback speed would also be desirable to quickly switch to the actual engagement speed once the desired mission time was acquired. ***The software should be equipped with quick access commands to reset observer point of view to default setups and to real-time speed. (R7)***

The tested version of the software used an internally calculated mission start time and then displayed the playback in terms of mission elapsed time. This made it difficult to synchronize the playback with an actual clock time. ***The playback time should be displayed in zulu time. (R8)***

Immediate access to a time of interest in the mission by selecting the desired zulu time of day would extensively enhance the ease of use of the software. ***Selection of playback starting time in zulu time of day format should be implemented for easy access to a flight time of interest. (R9)***

Items were identified whose impact on the performance of the SACTS as a debriefing tool was considered secondary, but would enhance the interpretation and value of the system. These were organized into the depiction of the aircraft and the depiction of the battlespace.

The use of more than two colors would provide the system easier interpretability in multiple force types of engagements. The use of a wider variety of representative aircraft shapes would provide an immediate cue to the position of all aircraft in the scenario. The fact that the aircraft was transparent led to some difficulty viewing the depth of the trajectory since it was at times cluttered by trajectory trails and ground traces. The trajectory trails in close-in combat were valuable, but restricted their length to a selectable number of seconds of flight (e.g., 1-15 in addition to 0) would allow the operator to optimize viewing. In order to provide an unmistakable indication of faulty data, trajectory trails and ground traces should be inhibited in addition to providing the currently implemented change in aircraft color when the position fix had degraded to 2D or below. Even though it was recommended to forego the development of the manual insertion of weapon employment information, it would be valuable identify aircraft which, in the determination of the operator, had been removed from the fight. The ACMI ranges used a tag in the form of a coffin to depict such aircraft. ***The depiction of the aircraft and aircraft trajectories should be improved. (R10)***

The implementation of the grid system at times allowed the engagement to extend beyond the grid reference (Figure 5). Although corrected by expanding the grid size, the smaller grid size was valuable when interpreting WVR engagements. The operator should at all times have the desired grid size displayed beneath the aircraft of interest. Also of value would be an altitude scale when viewing the combat from the vertical view as in Figure 6, to provide the same relative distance reference as the gridlines in the God's-eye depiction. The implementation of some simple landmark features into the grid system may also provide enhanced situational awareness when debriefing missions. ***The depiction of the battlespace should be improved. (R11)***

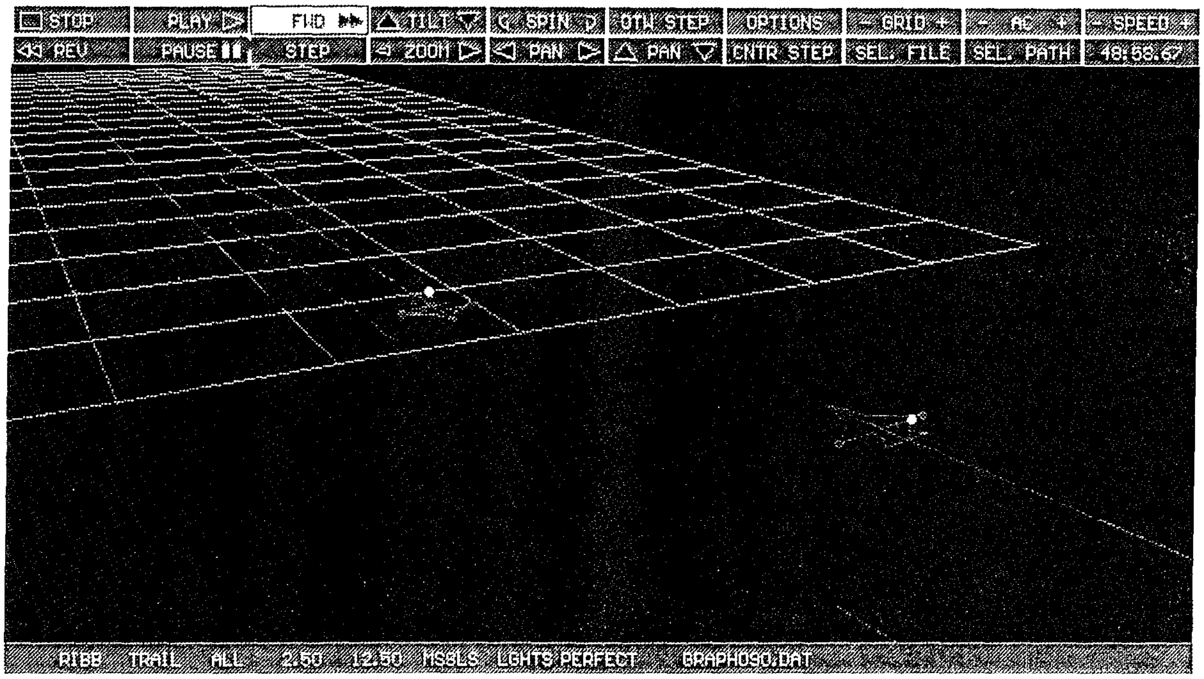


Figure 5 Limitation of Grid System Displayed in God's-Eye View

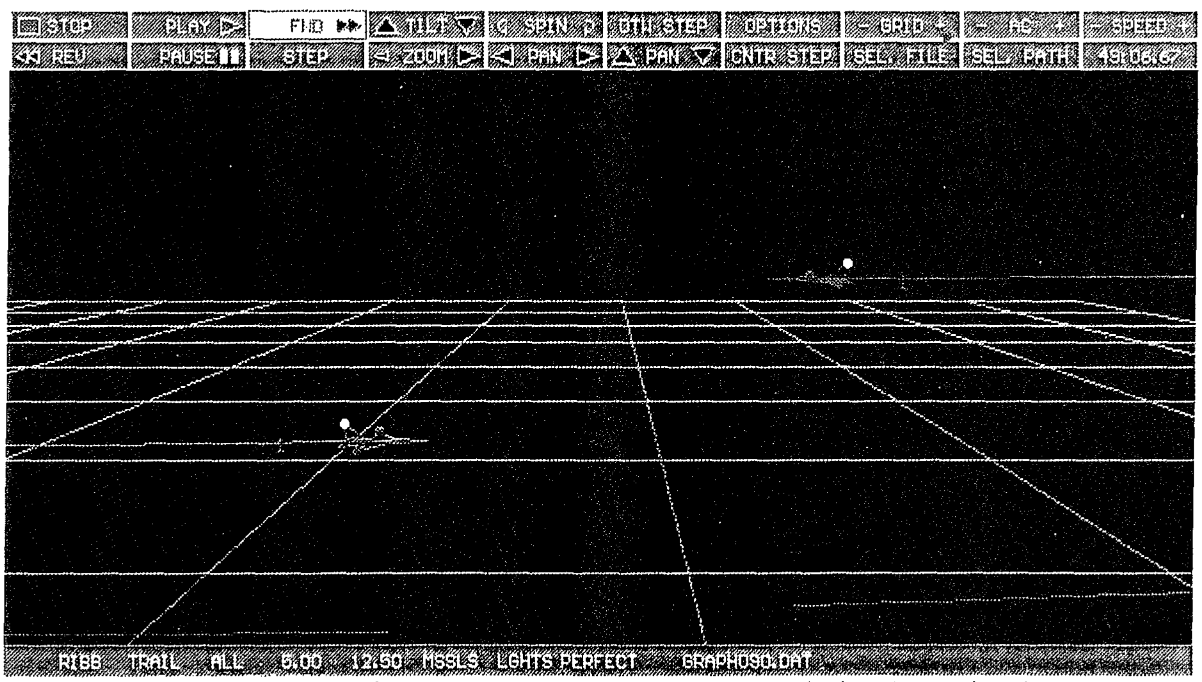


Figure 6 Vertical View of BVR Engagement - Approximately Coaltitude Aircraft

CONCLUSIONS AND RECOMMENDATIONS

All test objectives were met. Overall, the Squadron Air Combat Training System (SACTS) concept held promise, but the current prototype hardware performance was unsatisfactory for immediate use in a USAF fighter squadron training environment. The postprocessing software provided a satisfactory reconstruction of the flightpath and acceptable aerodynamic parameters given an accurate global positioning system (GPS) position solution. The visualization program provided the pilot with a simple and useful tool to debrief air combat engagements. In addition, although the detailed results are classified, the SACTS hardware was found to be incompatible with operationally representative F-16 aircraft.

The deficiency in the prototype hardware was its inability to maintain a GPS position fix during aggressive vertical maneuvering. The data suggested that the weakness could have been the result of a combination of GPS inaccuracies in the vertical axis and constellation blanking during these types of maneuvers. Additional antenna locations may also reduce the constellation masking phenomena in dynamic attitudes.

1. The ability of the GPS receiver to maintain position tracking through operationally representative maneuvers should be improved. (Page 7)

Recognizing the importance of timely mission debriefs in the operational environment made the relatively long processing time for the postflight processor an issue in terms of its suitability.

3. Processing time should be reduced such that debriefs would begin in less than approximately 40 minutes for typical 1 hour, 4 versus 4 engagements. (Page 10)

The accuracy of the postflight reconstruction suffered somewhat from the inability to account for winds on the aircraft's attitude and flightpath. This was especially true for within visual range engagements.

2. The system should be provided with a simple method to account for wind effects on the trajectory reconstruction. (Page 8)

While the software could provide a significant capability and a useful tool at the squadron level, some modifications were considered necessary before it could be deemed fully satisfactory for use in the training environment.

5. Closure velocity, range, and antenna train angle information should be provided for the two aircraft closest in range and, by selection, between any two aircraft in the engagement. (Page 10)

6. Basic playback commands should be modified to mimic standard videocassette recorder (VCR) equipment operation. (Page 11)

8. The playback time should be displayed in zulu time. (Page 11)

9. Selection of playback starting time in zulu time of day format should be implemented for easy access to a flight time of interest. (Page 11)

7. The software should be equipped with quick access commands to reset observer point of view to default setups and to real-time speed. (Page 11)

Items were identified whose impact in performance of the SACTS as a debriefing tool was considered secondary but would enhance the interpretation and value of the system. Items included providing a wider variety of colors and shapes for aircraft, decluttering trajectory trails and making the aircraft stand out against the grid and trail system, and enhancing the recognition of faulty data and aircraft removed from the engagement.

10. The depiction of the aircraft and aircraft trajectories should be improved. (Page 11)

Some modifications to the depiction of the area in which the engagement was playing were also identified to provide the operator with additional situational awareness. These items included increasing the flexibility of the grid system to ensure all grid sizes were available to the operator, providing an altitude scale in the vertical view, and adding simple landmark features into the display.

11. The depiction of the battlespace should be improved. (Page 11)

Finally, the implementation of the weapon employment information added additional processing time and, coupled with the limitations on the accuracy of the system, added little value to the debriefing tool.

4. The manual insertion of weapon employment information should not be pursued. (Page 10)

In summary, while the current SACTS equipment was unsatisfactory for its intended role, the concept of using recorded GPS to reconstruct air combat engagements at the squadron level held significant promise. If the challenges encountered during this test program could be overcome, further testing would be warranted and recommended.

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8. Bailey, William D., Captain, USAF, *Investigation of Using Global Positioning System for Air Data System Calibration of General Aviation Aircraft (HAVE PACER II)*, AFFTC-TR-95-76, Air Force Flight Test Center, Edwards AFB, California, January 1996.

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APPENDIX A

DETAILED TEST ITEM DESCRIPTION

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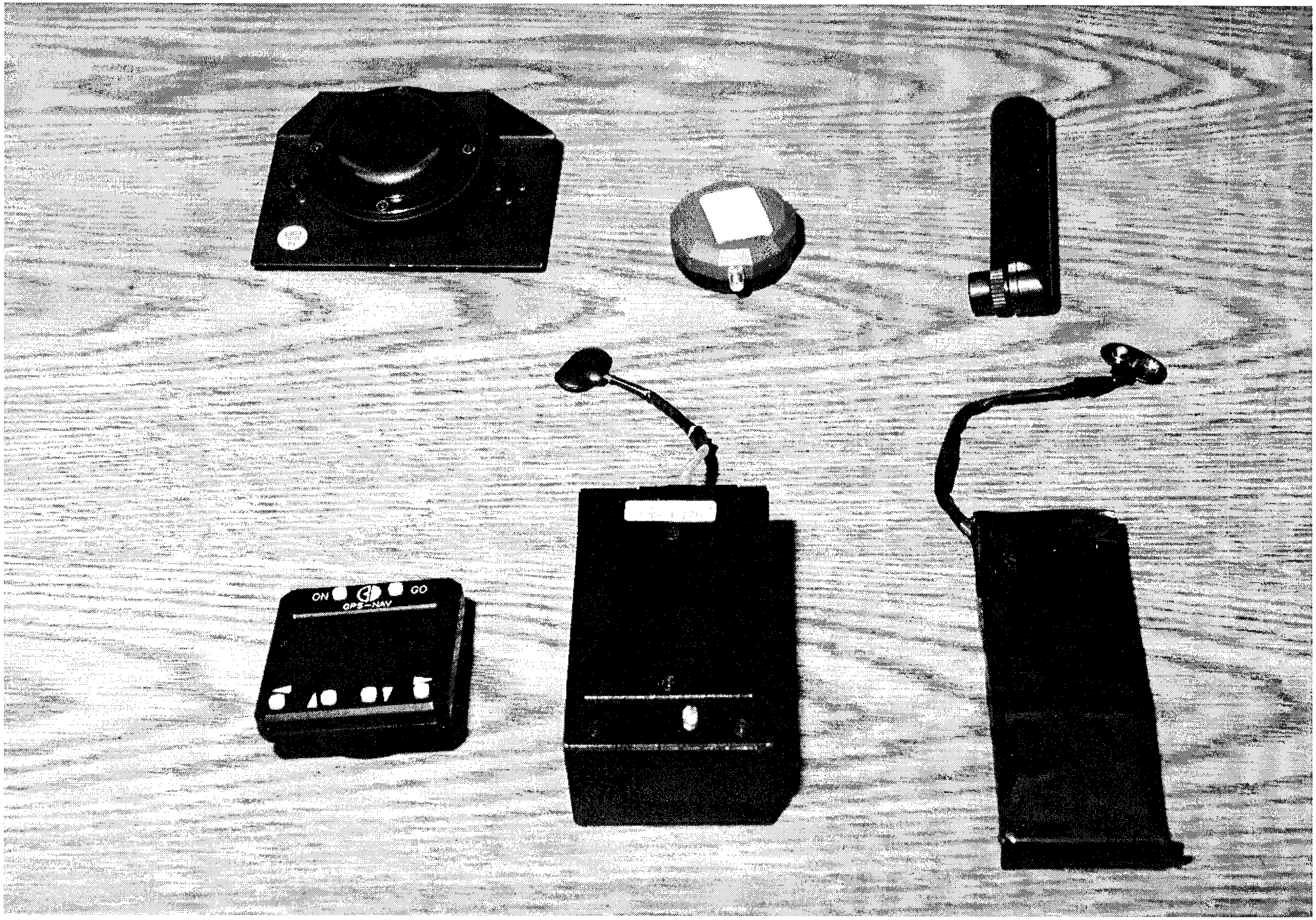

Figure A1 Squadron Air Combat Training System Hardware

Table A1

GPS NAVIGATOR AND SECURE FLIGHT RECORDER DESCRIPTION

Size	5.5 in long, 2.7 in wide, 1.9 in high
Connector	BNC
Weight	0.8 lb
Power	External 12 to 14 volts or power supply Current drain: 170 mA with 1 LCD display
Logging interval	1 sec min up to 32 sec; PC configurable
MAX flight time	3 hr at 1-sec logging interval

Notes: 1. GPS - global positioning system
2. BNC - Bayonet-Neil-Councelman
3. LCD - liquid crystal display
4. PC - personal computer
5. mA - milliamperes

Table A2

LCD DISPLAY AND CONTROL UNIT DESCRIPTION

Size	2.6 in long and high, 1.27 in wide
Connector	6-wire telephone jack
Weight	0.35 lb
Power	15 mA at 12 volts

Notes: 1. LCD - liquid crystal display
2. mA - milliamperes

Table A3
GARMIN GPS 25 PHASETRAC 12™ RECEIVER

Performance	Architecture	12 parallel channel
	Time to first fix	Reacquisition: less than 2 sec
		Warm: 15 sec
		Cold: 45 sec
		Auto Locate: 90 sec
		Sky Search: less than 5 min
		Update rate: 1/sec, continuous
	Accuracy	Position: 15 m RMS
		Velocity: 0.1 m/sec
	Dynamics	Velocity: 999 kt
		Acceleration: 6 g, 60 m/sec^2
	Datums	102 predefined, 1 user defined
Electrical	Input Voltage	5.0 volts dc ±5 pct regulated
	Power	11W (typical)
	Backup	Onboard 3-volt lithium battery (10-year life)
	Sensitivity	-166 dBW
Connectors	Antenna	50 Ohm MCX female connector for active antenna (5 volts dc and 15 mA) or passive antenna
	Power / Data	Single row, right angle 12-pin male
Physical	Configuration	1 board integrated engine
	Size	1.83 in wide, 2.75 in long, 0.45 in high
	Weight	11 oz
	Operating temperature	-30 to 85 deg C
	Storage temp.	-40 to 85 deg C
Interfaces	Compatibility	Two RS-232 serial ports
	Data Rate	User selectable: 1200, 2400, 4800, or 9600 Baud
	Format	NMEA 0183 versus 2.0 ASCII
	Inputs	Initial position, date and time (not required), 2D/3D and earth datum command, RTCM-104 versus 2.0
	Outputs	Position, velocity and time, receiver and satellite status, geometry and error estimates
	PPS output	1 PPS timing output with ±1 μs accuracy

Notes:
1. GPS - global positioning system
2. RMS - root mean square
3. dc - direct current
4. dBW - decibel, watts
5. MCX - miniature connector
6. mA - milliamperes
7. oz - ounce
8. NMEA - National Marine Electronics Association
9. ASCII - American Standard Code for Information Interchange
10. 2D - two dimensional
11. 3D - three dimensional
12. RTCM - Radio Technical Commission for Maritime
13. PPS - precision positioning system
14. μs - microseconds

Table A4
ANTENNA CABLE DESCRIPTION

Type	Coaxial
Connectors	1 BNC and 1 SMA (female type)
Length	4.0 ft
Manufacturer	Teledyne Thermatics
Part Number	M17/158-00001
Military Specifications	MIL-C-17 12515

Notes: 1. BNC - Bayonet-Neil-Councelman
2. SMA - subminiature adapter

Table A5
ROCKWELL COLLINS PLGR ANTENNA NUMBER 013-1925-030

Antenna	Operating Frequency	1,575.42 ±10 MHz
	Gain	-3.0 dB min referenced to a right hand circularly polarized isotropic radiator for elevation angles above 10 deg above the horizon (i.e., a 160 deg solid cone)
	Impedance	50 ohms nominal
Amplifier and Preselector	Gain	26.5 ±2 dB at 1,575.42 ±10 MHz (excluding the antenna)
	Noise Figure	2.5 dB MAX over the operating frequency (excluding the antenna)
	Bandwidth including the antenna	±5 MHz, 1 dB MAX 1575.42 ± 10 MHz, 2 dB MAX
	Output 1 dB Compression Point	-15 dBm min
	Supply Voltage	4.5 to 5.5 volts at input to cable
	Supply Current	40 mA MAX
	Supply Ripple	50 mV MAX
Connector	N/A	The connector shall be a SMA series receptacle (female contact) in accordance with MIL-C-39012. A commercial equivalent is acceptable.
Magnet Mount	N/A	The magnet shall secure the unit to the metal roof of a vehicle when exposed to a 70 mph wind.

Notes: 1. PLGR - portable lightweight global positioning system receiver
2. dB - decibels
3. ohms - electric resistance
4. dBm - decibel referenced to milliwatts
5. mA - milliamperes
6. mV - millivolts
7. SMA - subminiature adapter
8. N/A - not applicable

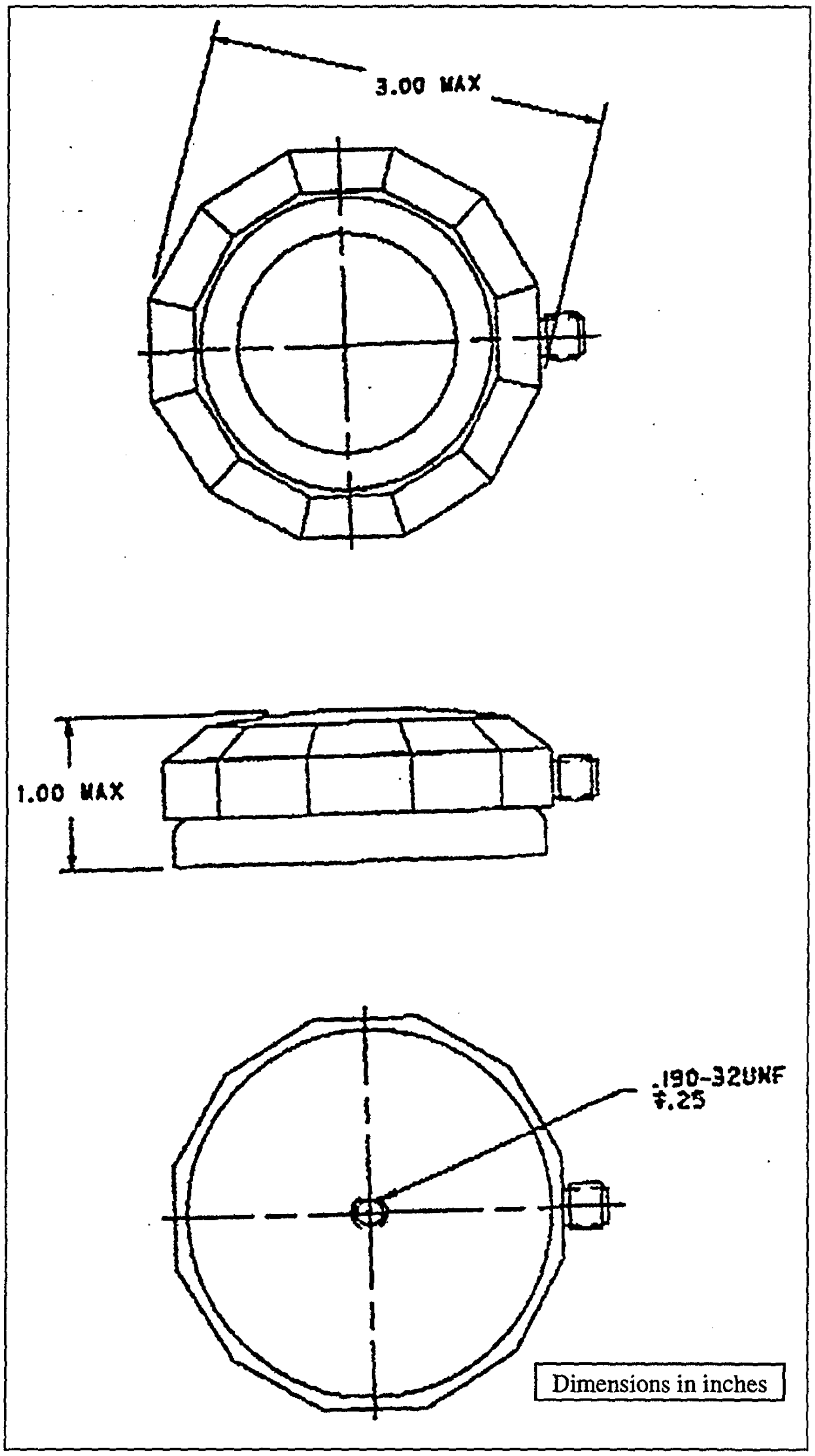

Figure A2 Rockwell Collins PLGR Antenna Number 013-1925-030

Figure A3 Front View of the Helmet/Vest Configuration

Figure A4 Side View of the Helmet/Vest Configuration

Figure A5 Antenna Position in T-38 Rear Cockpit

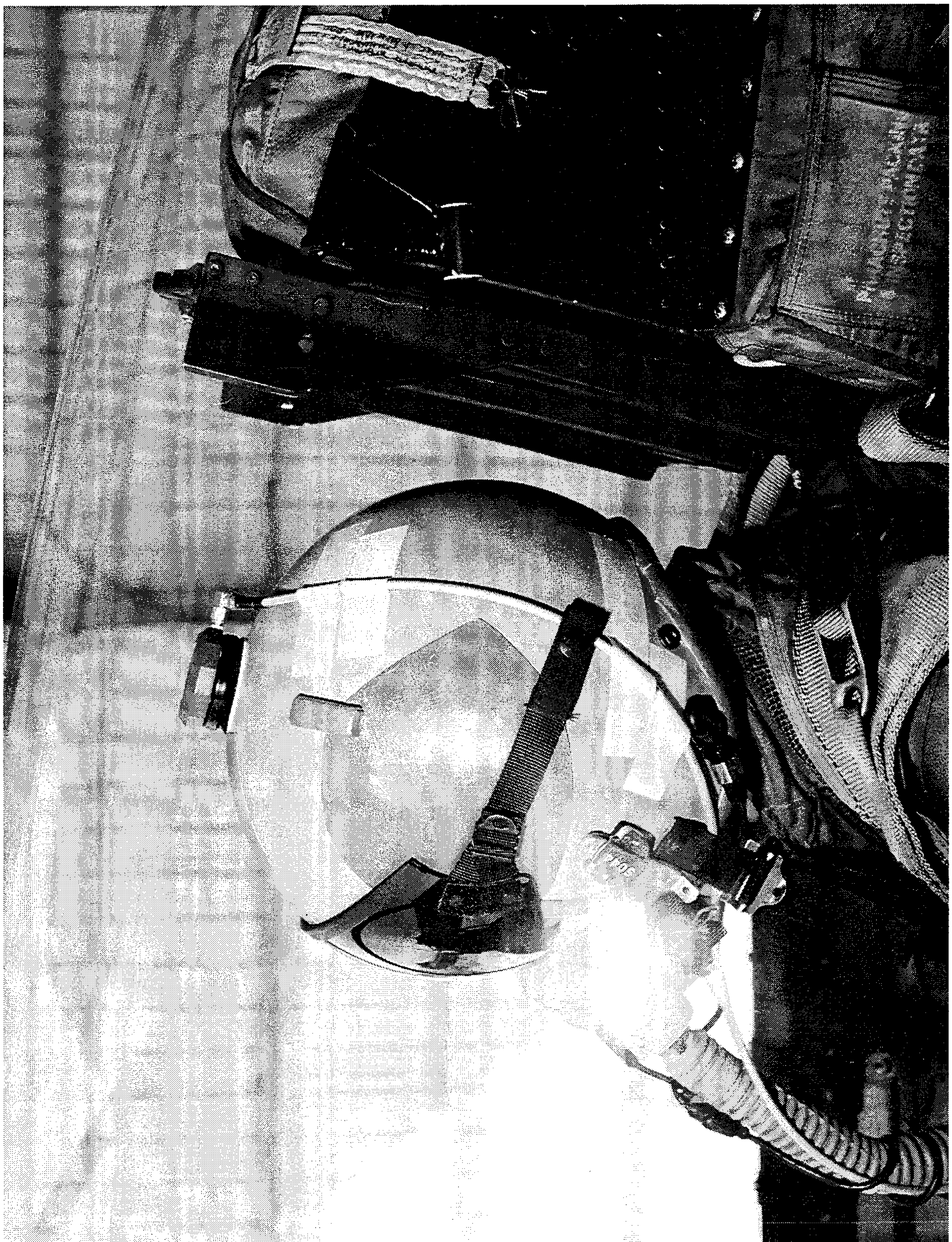

Figure A6 Antenna Position in F-15B Rear Cockpit

Figure A7 Antenna Position in F-16B Rear Cockpit

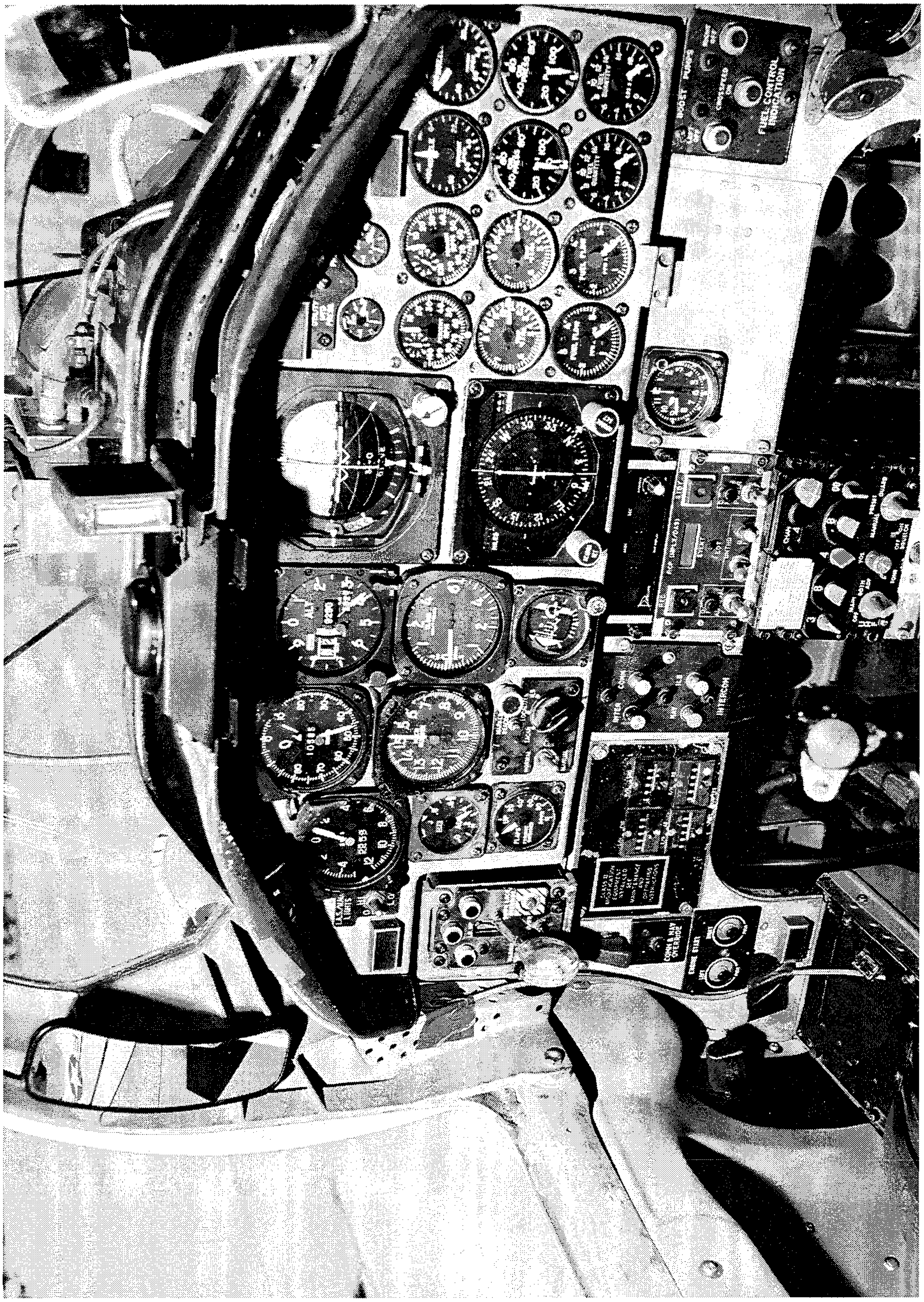

Figure A8 Glareshield-Mounted Antenna Location in T-38 Rear Cockpit

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APPENDIX B

SUPPORTING DATA

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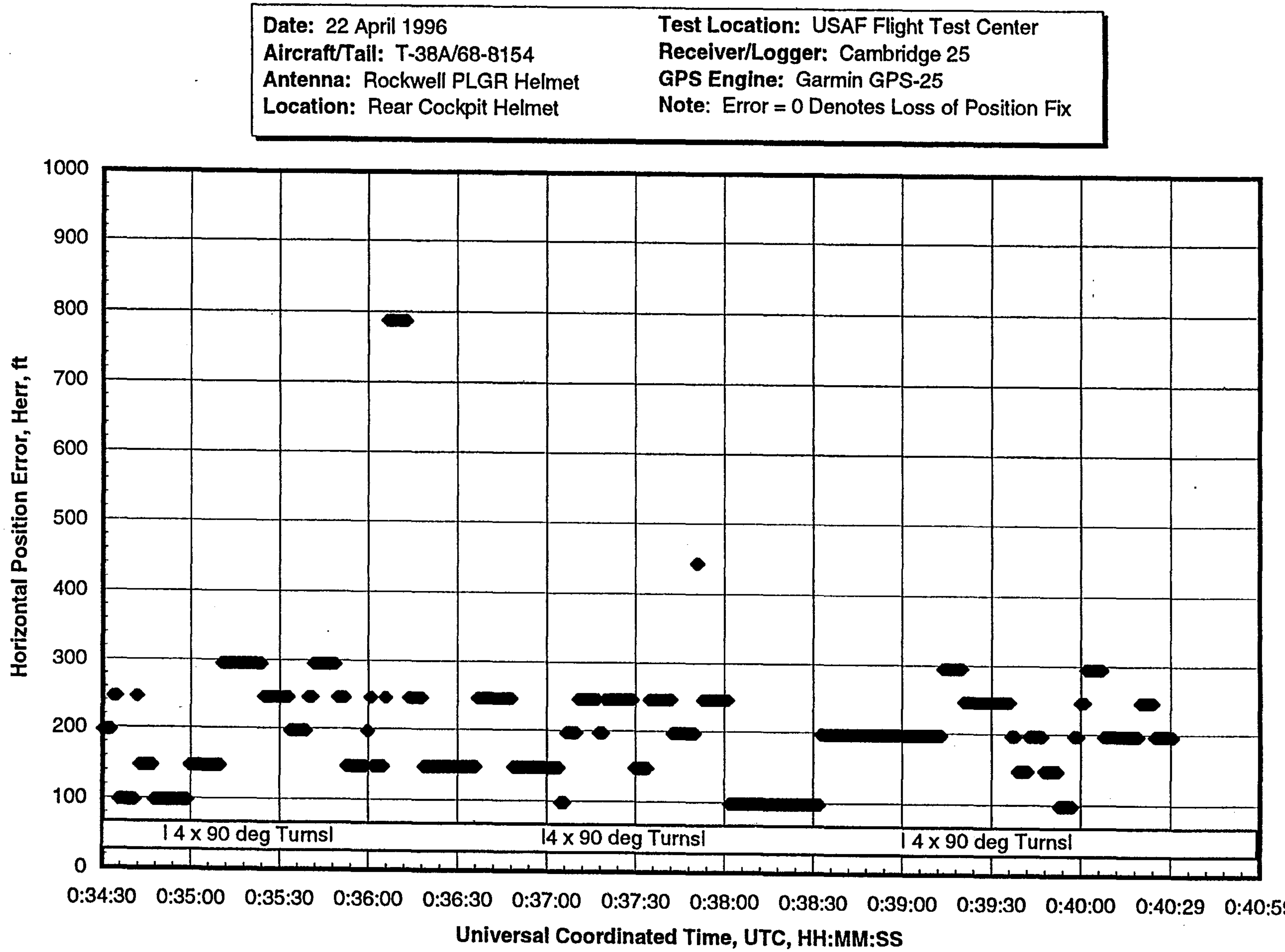

Figure B1 GPS Horizontal Error During 4-g Level Turns

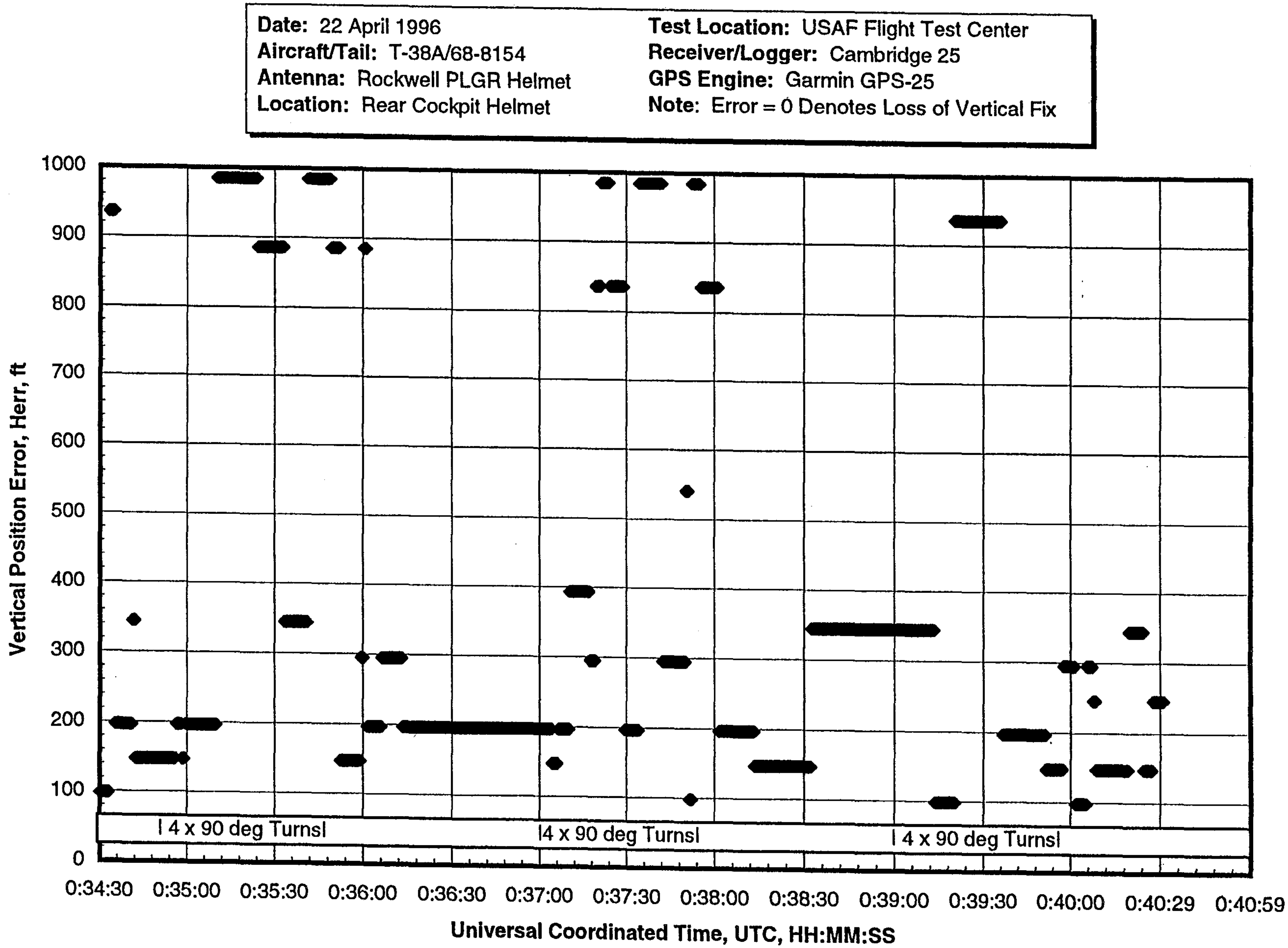

Figure B2 GPS Vertical Error During 4-g Level Turns

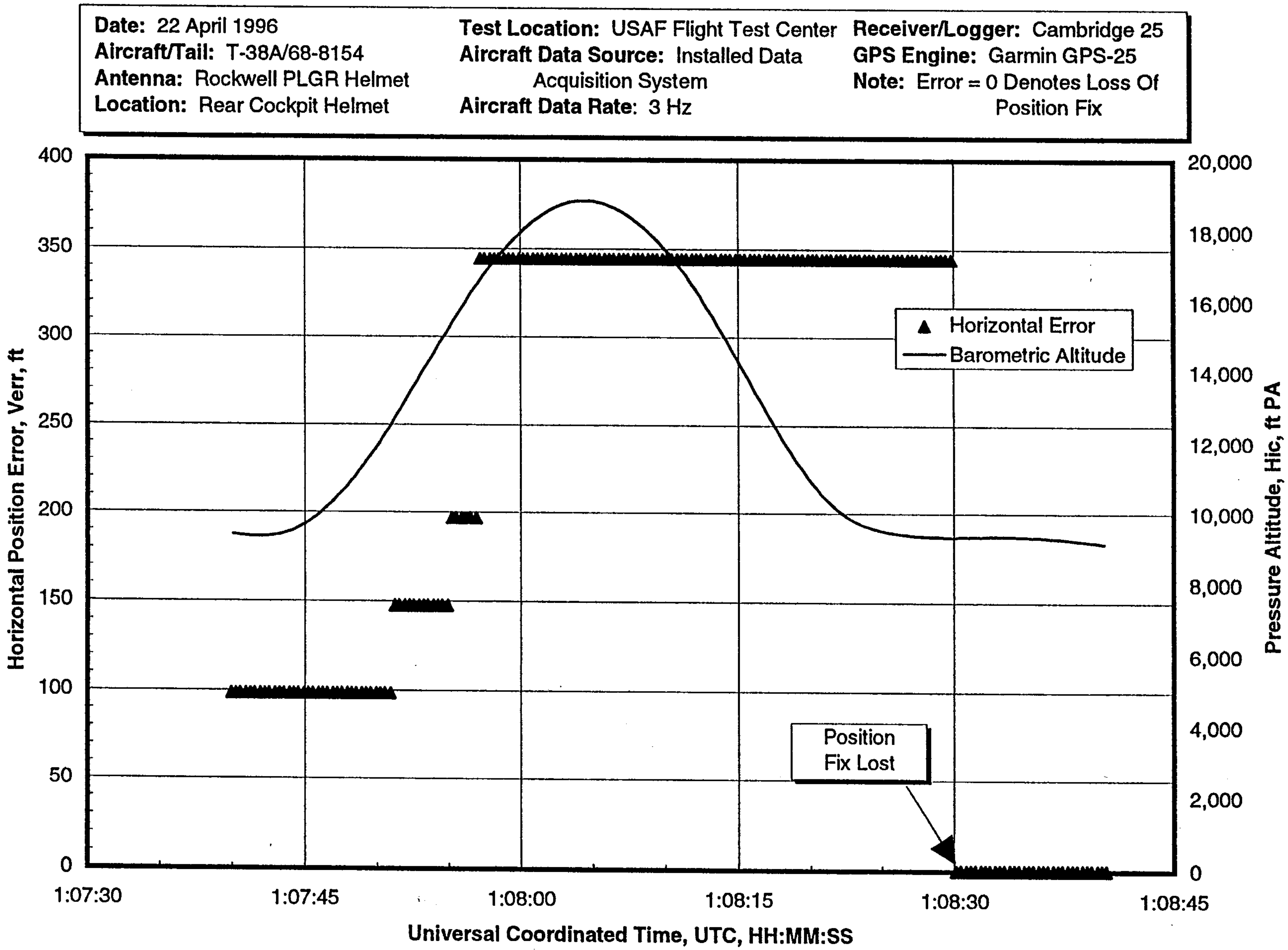

Figure B3 GPS Horizontal Error During Clover Leaf Maneuver

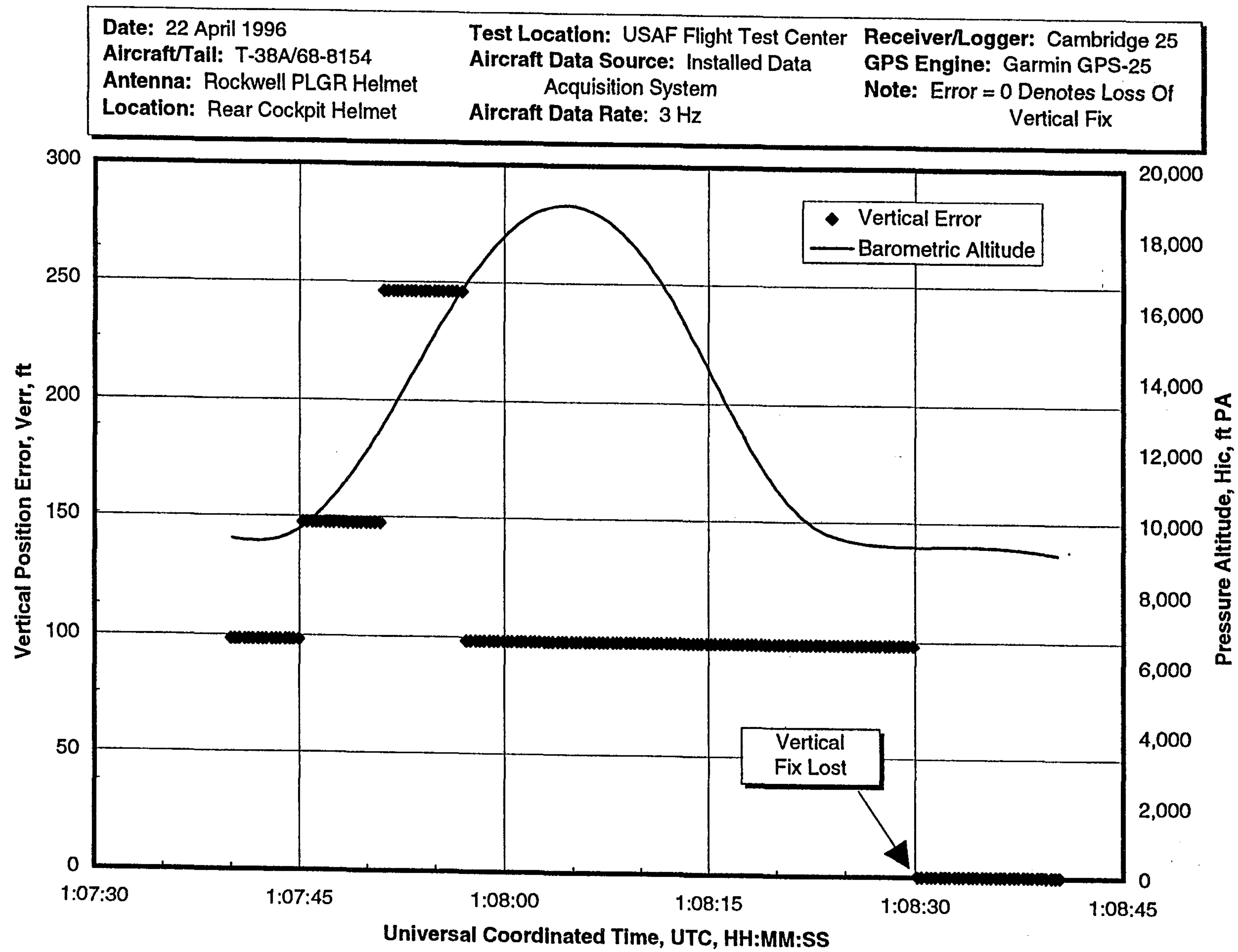

Figure B4 GPS Vertical Error During Clover Leaf Maneuver

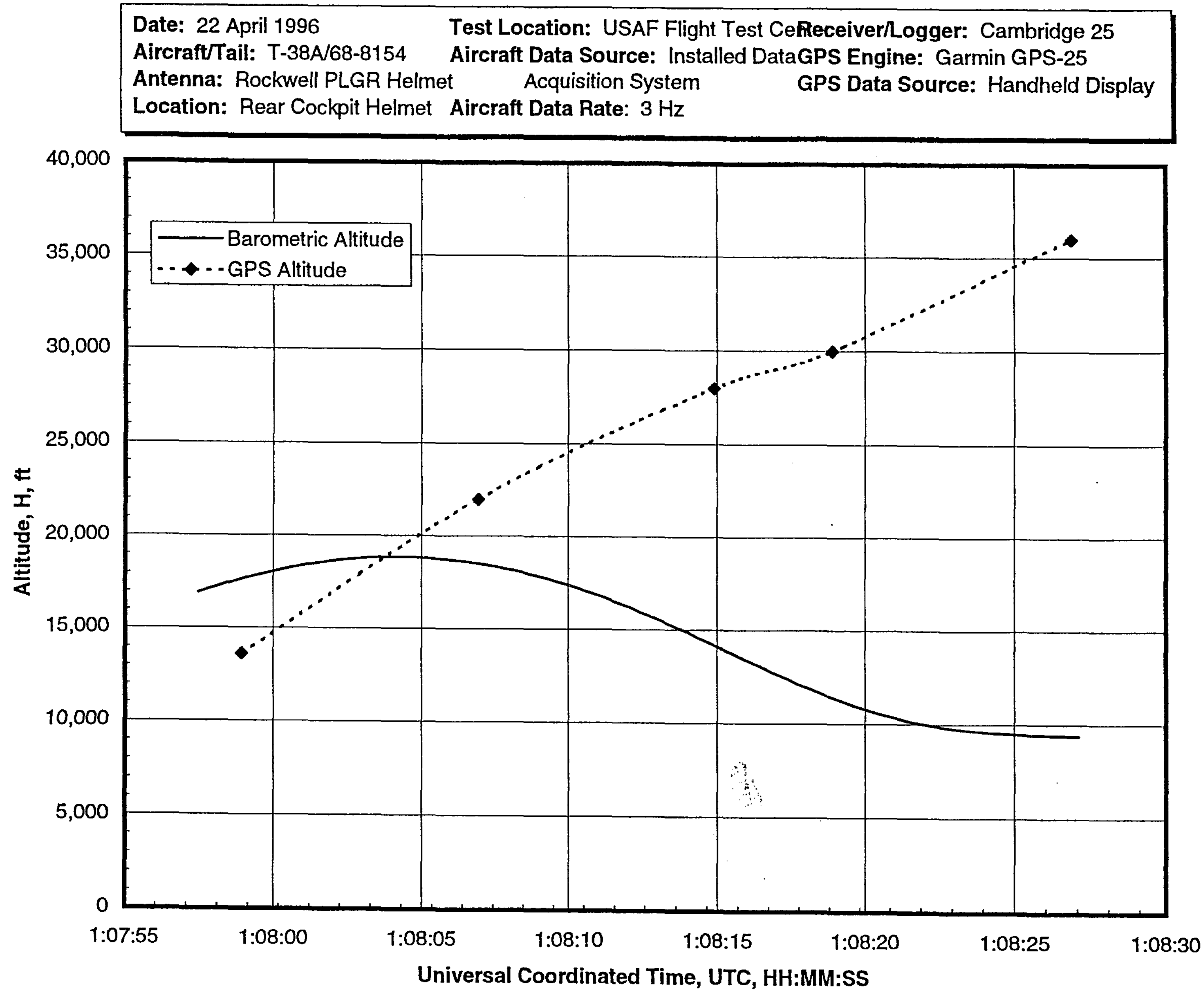

Figure B5 GPS Altitude Behavior During Clover Leaf Maneuver

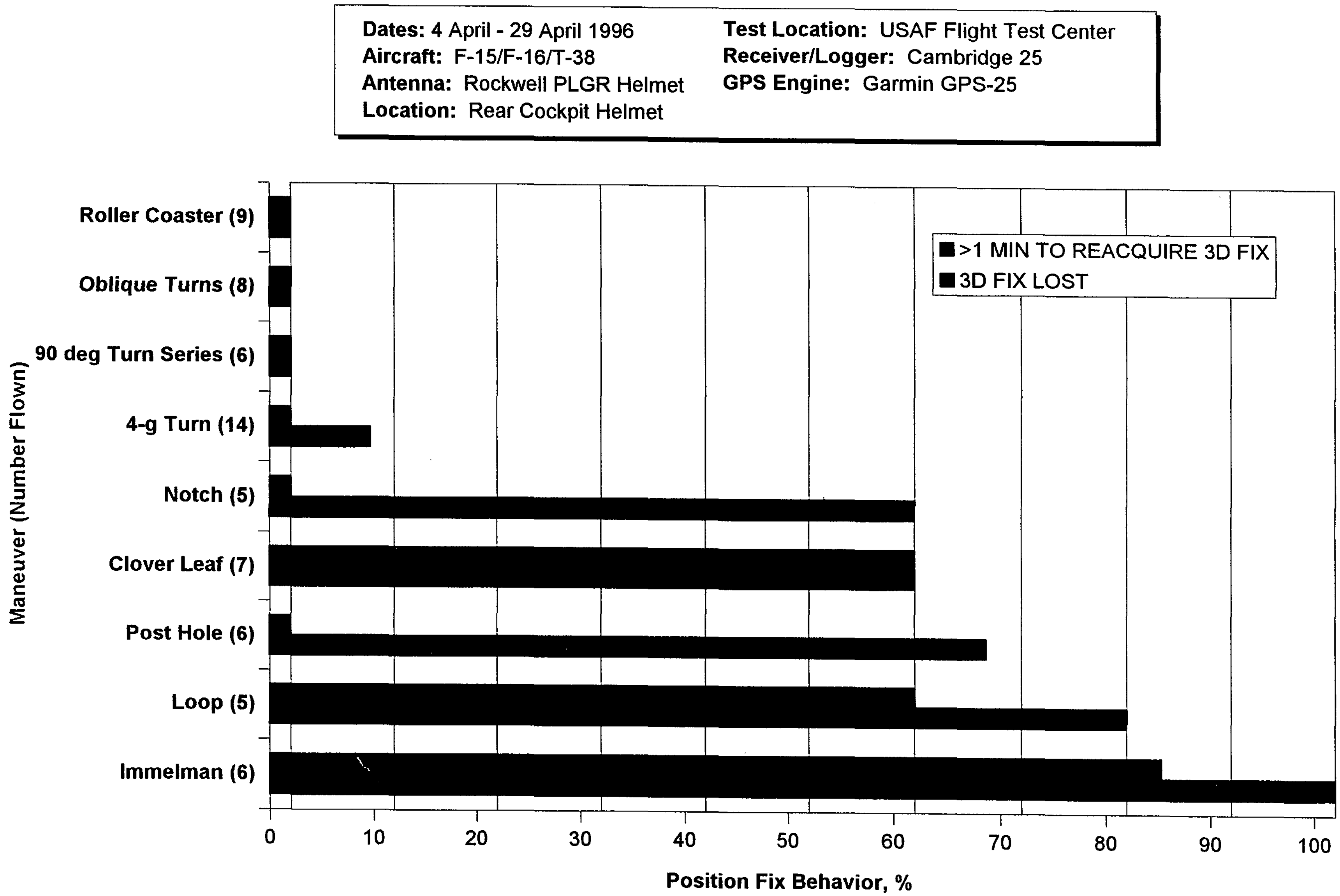

Figure B6 Database of Position Fix During Operational Maneuvers

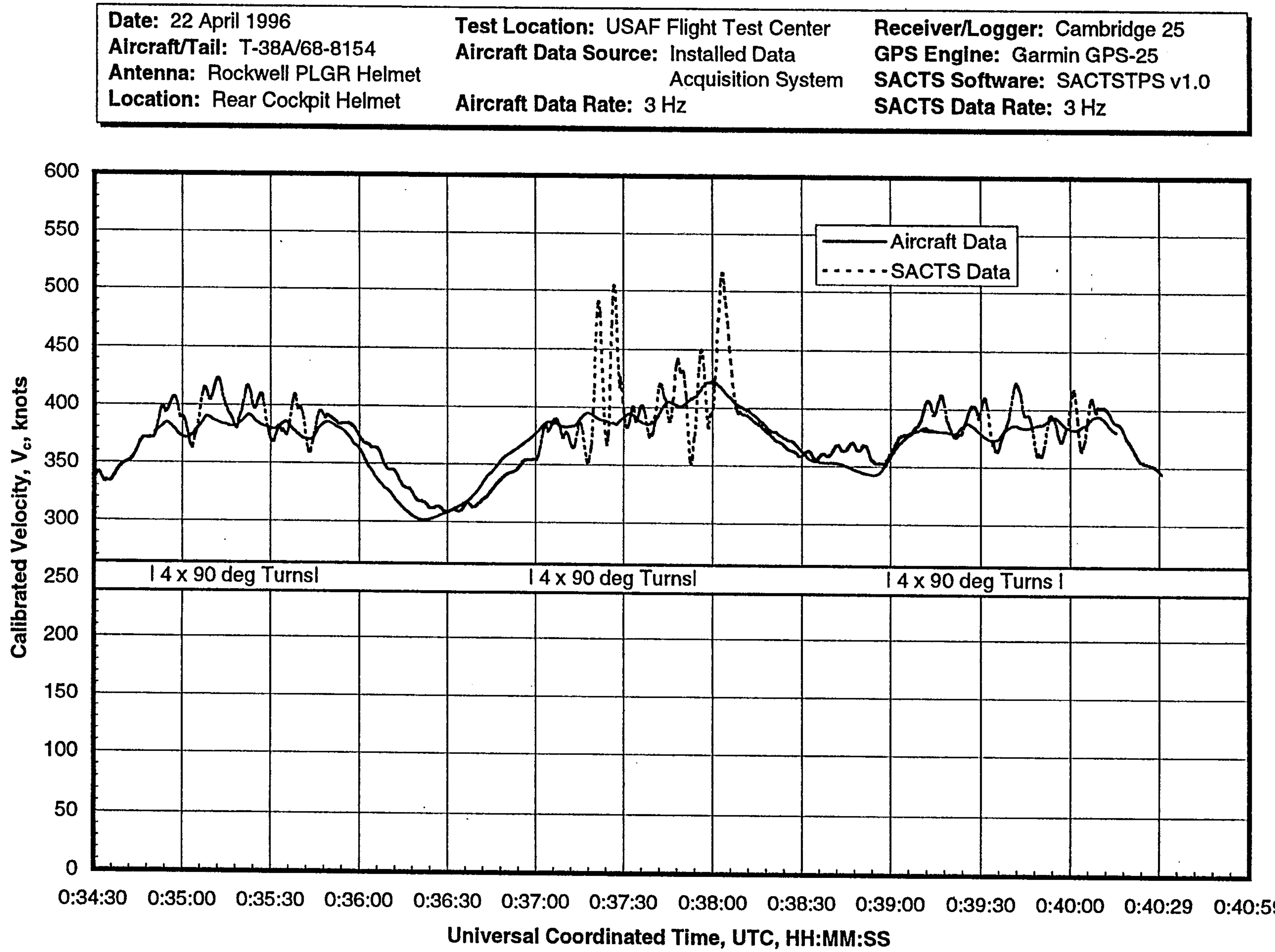

Figure B7 Velocity Correlation During 4-g Level Turns

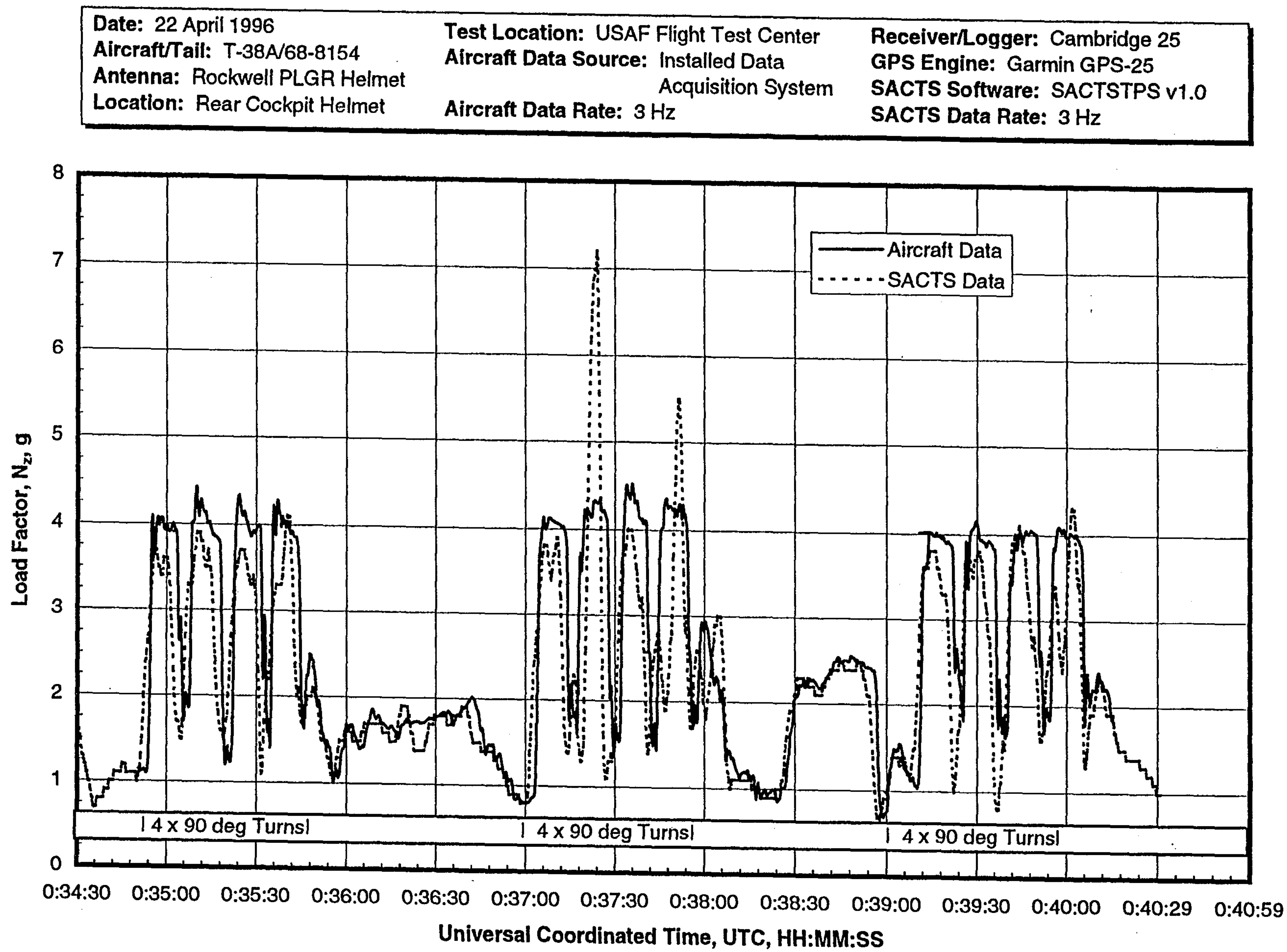

Figure B8 Load Factor Correlation During 4-g Level Turns

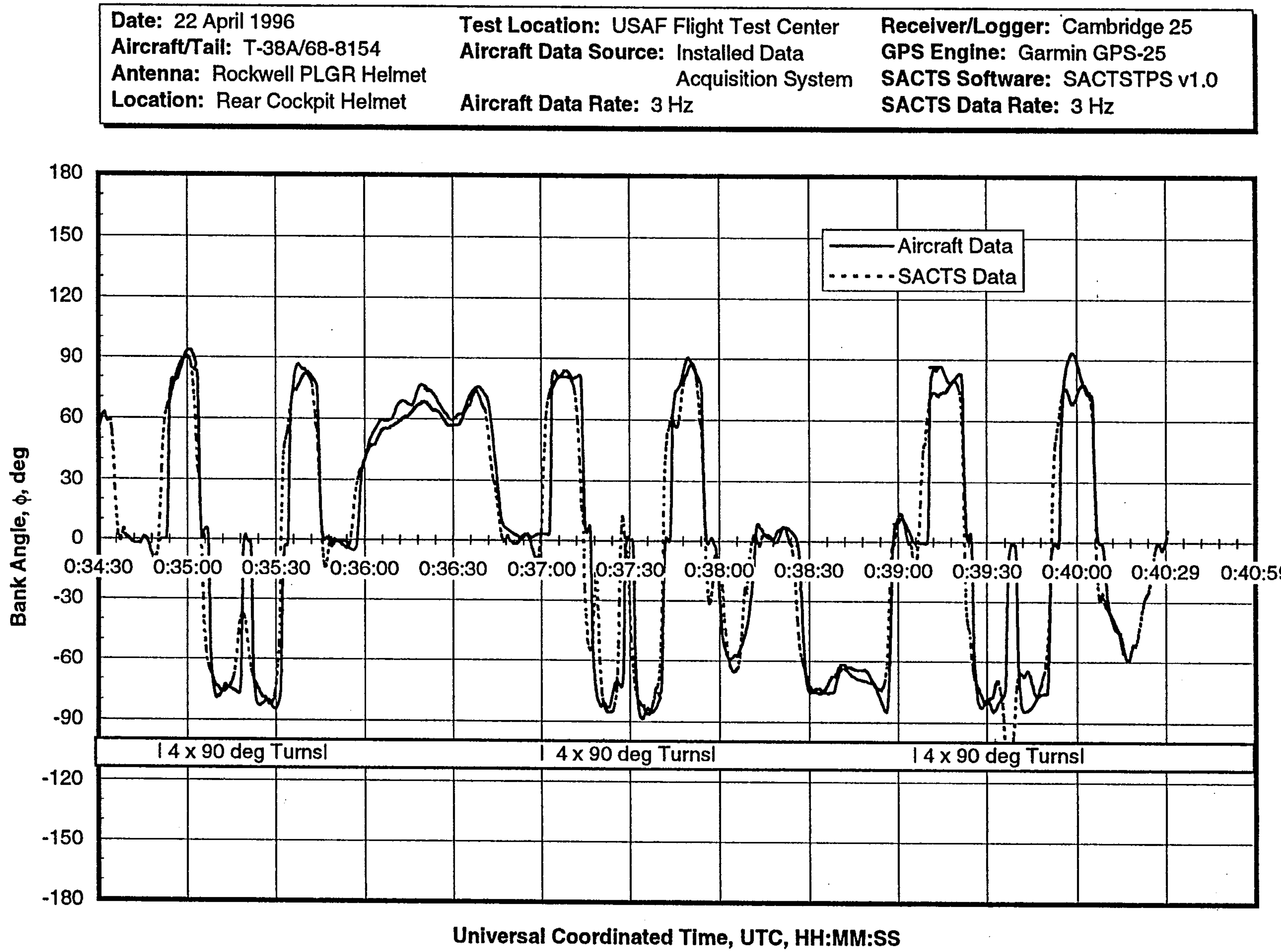

Figure B9 Bank Angle Correlation During 4-g Level Turns

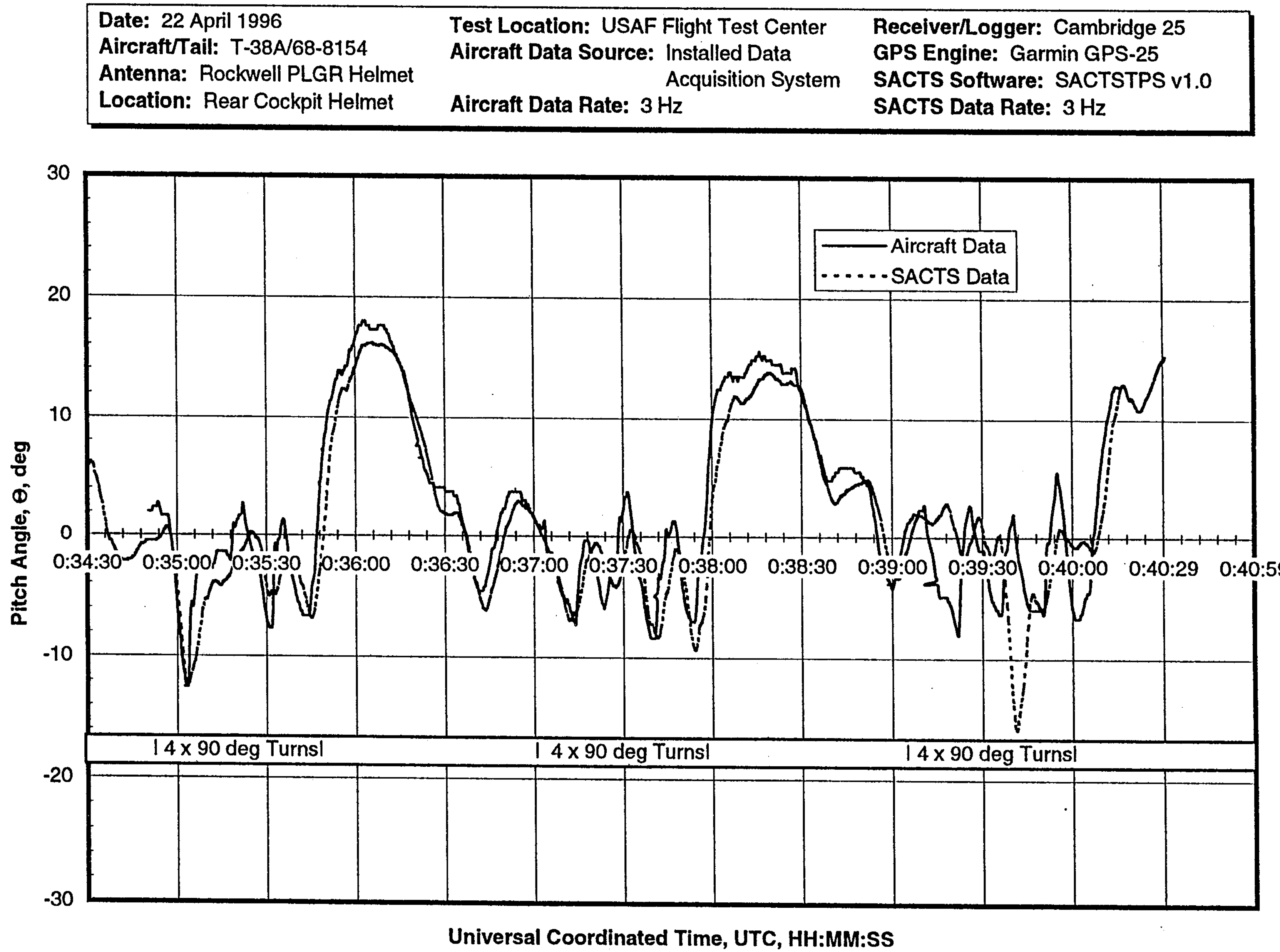

Figure B10 Pitch Angle Correlation During 4-g Level Turns

Date: 22 April 1996	**Test Location:** USAF Flight Test Center	**Receiver/Logger:** Cambridge 25
Aircraft/Tail: T-38A/68-8154	**Aircraft Data Source:** Installed Data Acquisition System (DAS)	**GPS Engine:** Garmin GPS-25
Antenna: Rockwell PLGR Helmet		**SACTS Software:** SACTSTPS v1.0
Location: Rear Cockpit Helmet	**Aircraft Data Rate:** 3 Hz	**SACTS Data Rate:** 3 Hz

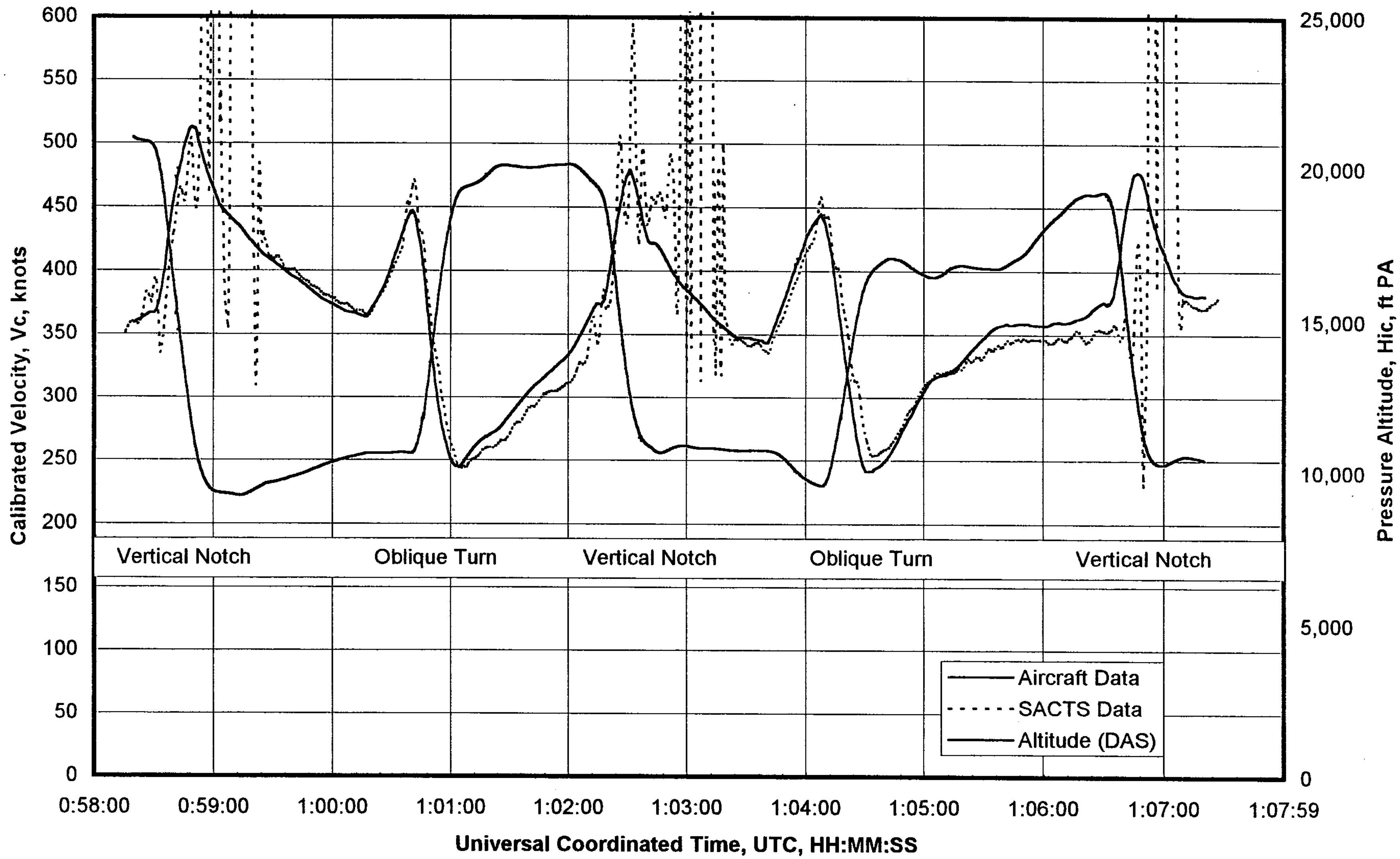

Figure B11 Velocity Correlation During Vertical Maneuvers

Date: 22 April 1996
Aircraft/Tail: T-38A/68-8154
Antenna: Rockwell PLGR Helmet
Location: Rear Cockpit Helmet

Test Location: USAF Flight Test Center
Aircraft Data Source: Installed Data Acquisition System (DAS)
Aircraft Data Rate: 3 Hz

Receiver/Logger: Cambridge 25
GPS Engine: Garmin GPS-25
SACTS Software: SACTSTPS v1.0
SACTS Data Rate: 3 Hz

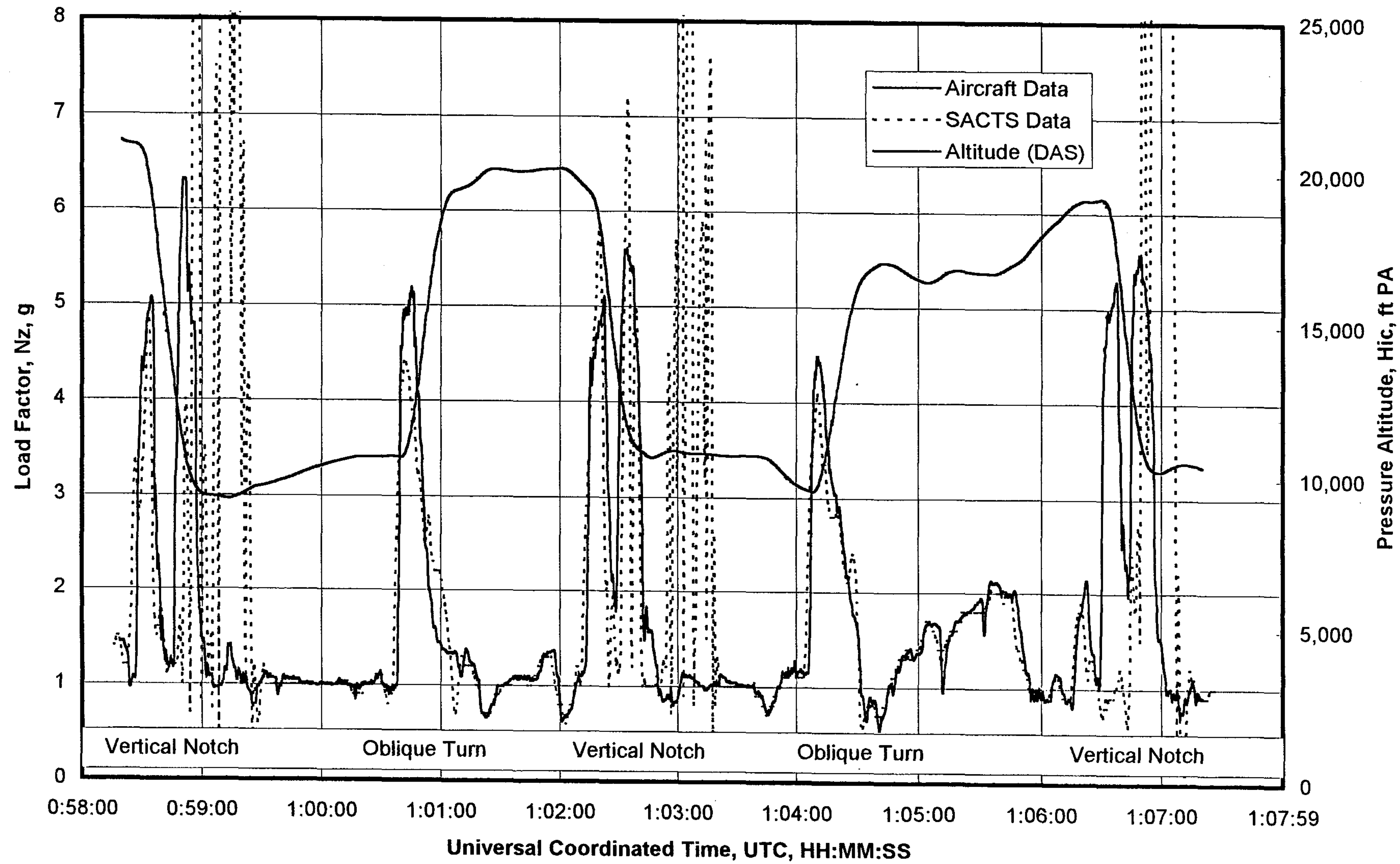

Figure B12 Load Factor Correlation During Vertical Maneuvers

Date: 22 April 1996
Aircraft/Tail: T-38A/68-154
Antenna: Rockwell PLGR Helmet
Location: Rear Cockpit Helmet

Test Location: USAF Flight Test Center
Aircraft Data Source: Installed Data Acquisition System (DAS)
Aircraft Data Rate: 3 Hz

Receiver/Logger: Cambridge 25
GPS Engine: Garmin GPS-25
SACTS Software: SACTSTPS v1.0
SACTS Data Rate: 3 Hz

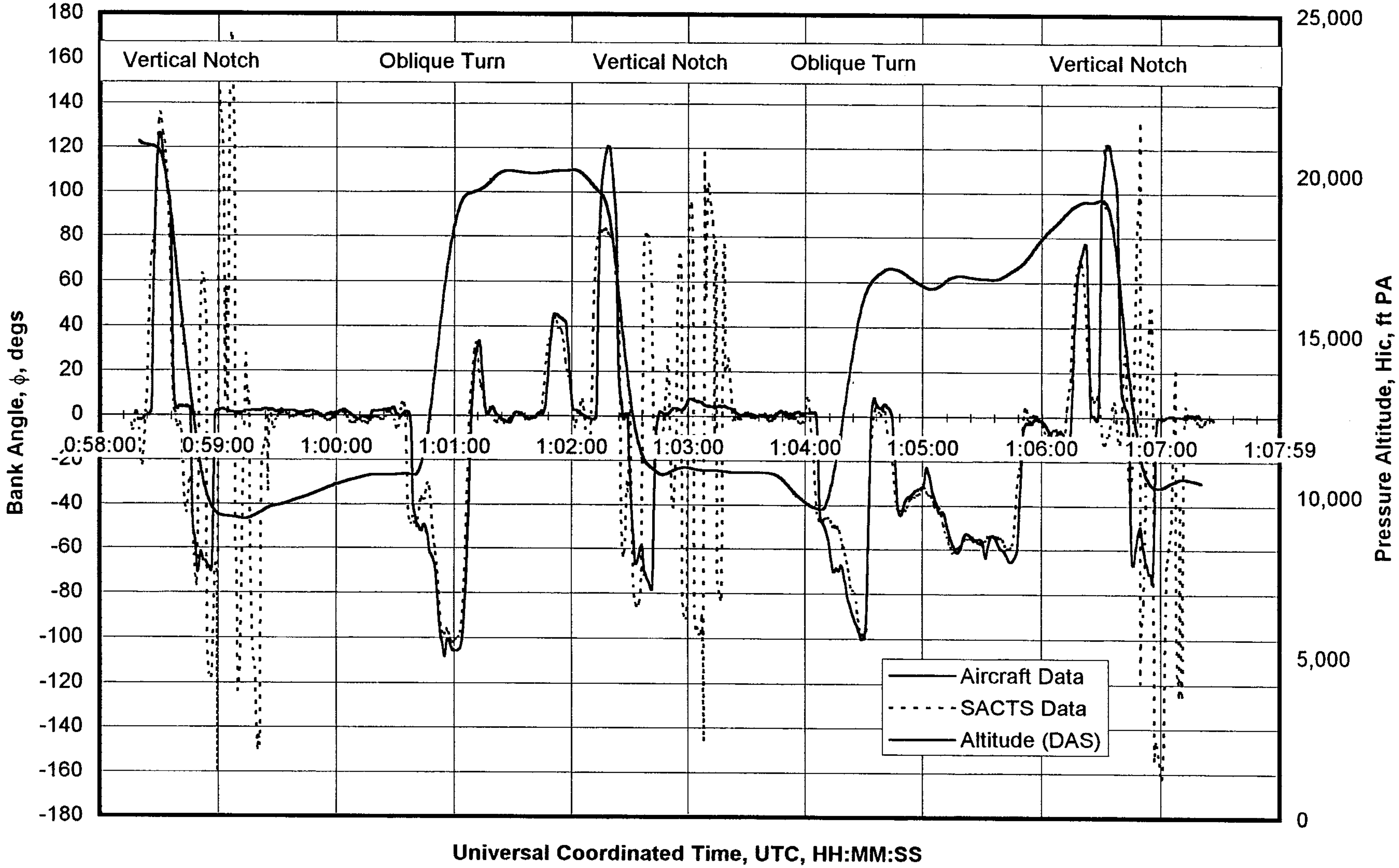

Figure B13 Bank Angle Correlation During Vertical Maneuvers

Date: 22 April 1996	**Test Location:** USAF Flight Test Center	**Receiver/Logger:** Cambridge 25
Aircraft/Tail: T-38A/68-8154	**Aircraft Data Source:** Installed Data Acquisition System (DAS)	**GPS Engine:** Garmin GPS-25
Antenna: Rockwell PLGR Helmet		**SACTS Software:** SACTSTPS v1.0
Location: Rear Cockpit Helmet	**Aircraft Data Rate:** 3 Hz	**SACTS Data Rate:** 3 Hz

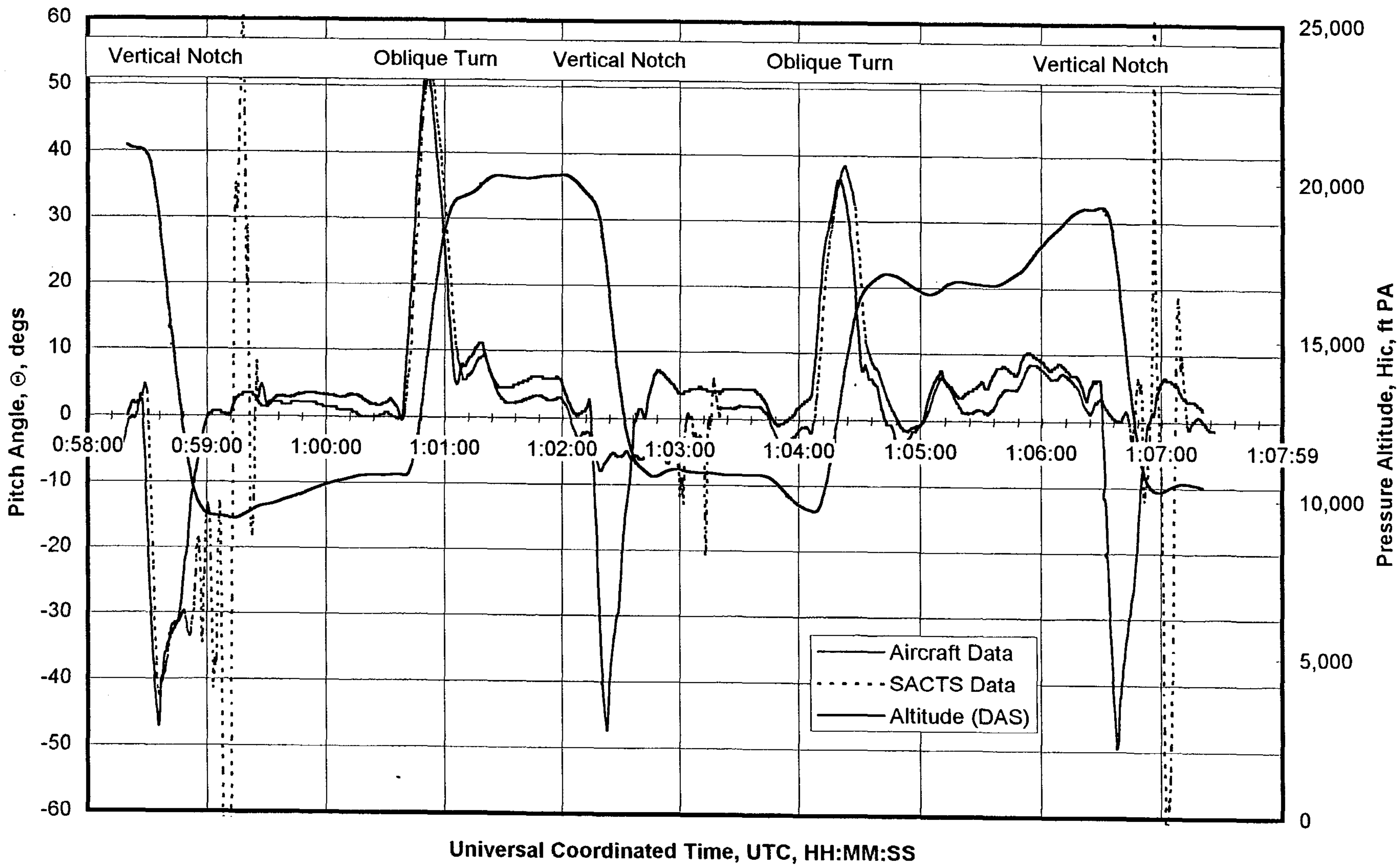

Figure B14 Pitch Correlation During Vertical Maneuvers

Date: 25 April 1996
Aircraft/Tail: T-38A/68-8154
Antenna: Rockwell PLGR Helmet
Location: Rear Cockpit Helmet

Test Location: USAF Flight Test Center
Aircraft Data Source: Installed Data Acquisition System
Aircraft Data Rate: 3 Hz

Receiver/Logger: Cambridge 25
GPS Engine: Garmin GPS-25
SACTS Software: SACTSTPS v1.0
SACTS Data Rate: 3 Hz

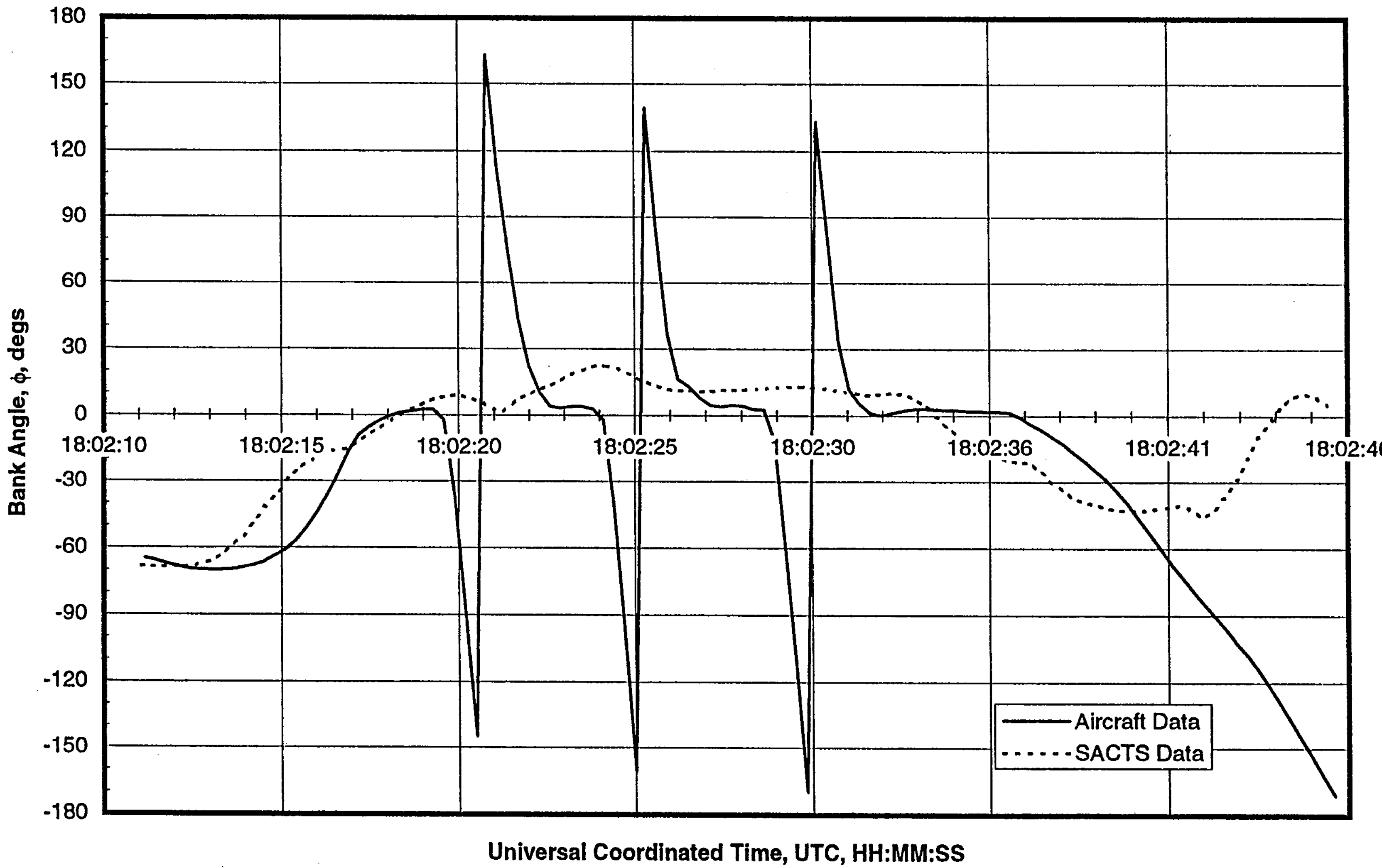

Figure B15 Bank Angle Correlation During Three Slow Aileron Rolls

Date: 25 April 1996
Aircraft/Tail: T-38A/68-8154
Antenna: Rockwell PLGR Helmet
Location: Rear Cockpit Helmet

Test Location: USAF Flight Test Center
Aircraft Data Source: Installed Data Acquisition System
Aircraft Data Rate: 3 Hz

Receiver/Logger: Cambridge 25
GPS Engine: Garmin GPS-25
SACTS Software: SACTSTPS v1.0
SACTS Data Rate: 3 Hz

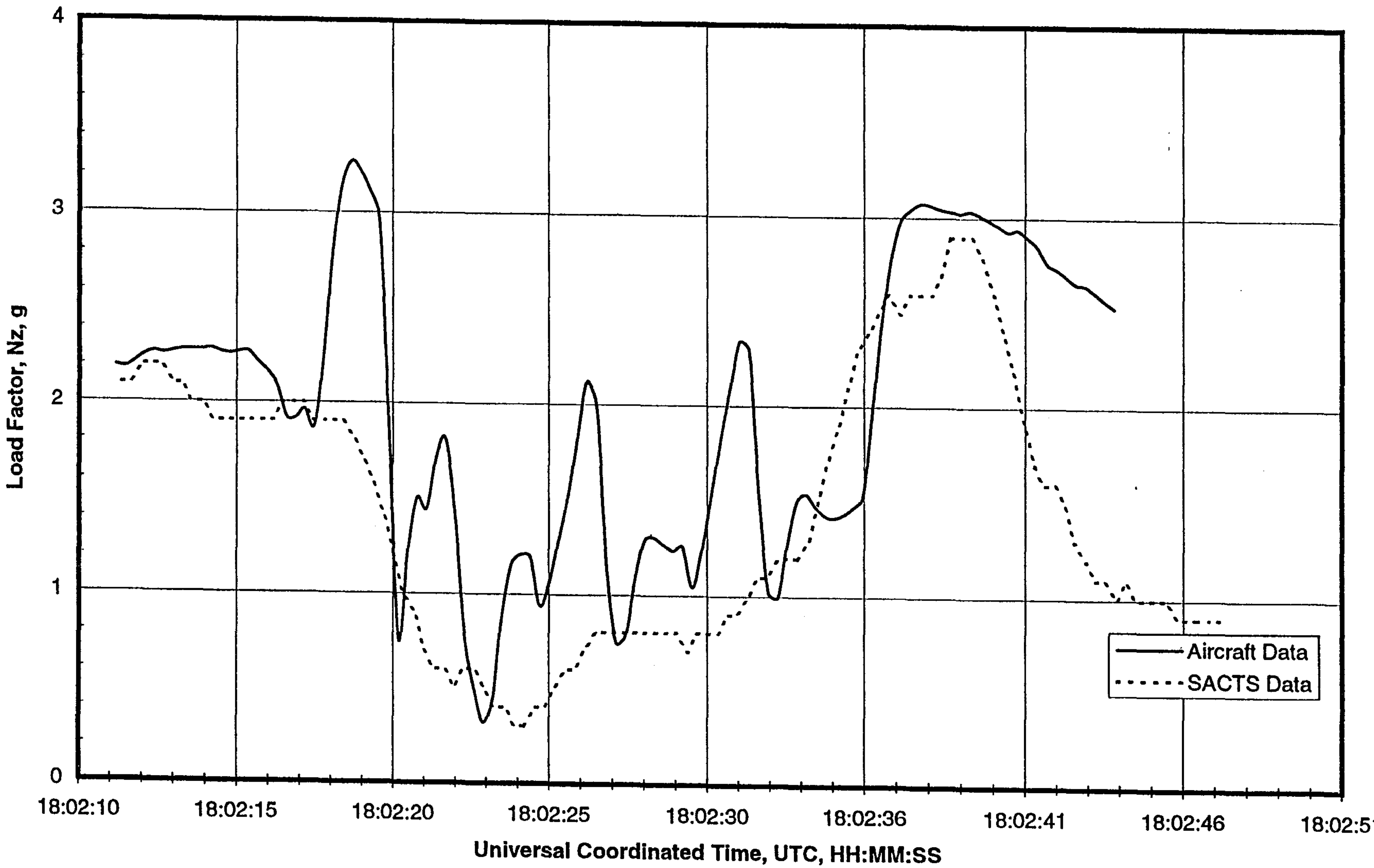

Figure B16 Load Factor Correlation During Three Slow Aileron Rolls

Date: 04 April 1996	**Test Location:** USAF Flight Test Center	**Receiver/Logger:** Cambridge 25
Aircraft/Tail: T-38A/68-135	**Aircraft Data Source:** Installed Data Acquisition System	**GPS Engine:** Garmin GPS-25
Antenna: Rockwell PLGR Helmet		**SACTS Software:** SACTSTPS v1.0
Location: Rear Cockpit Helmet	**Aircraft Data Rate:** 3 Hz	**SACTS Data Rate:** 3 Hz

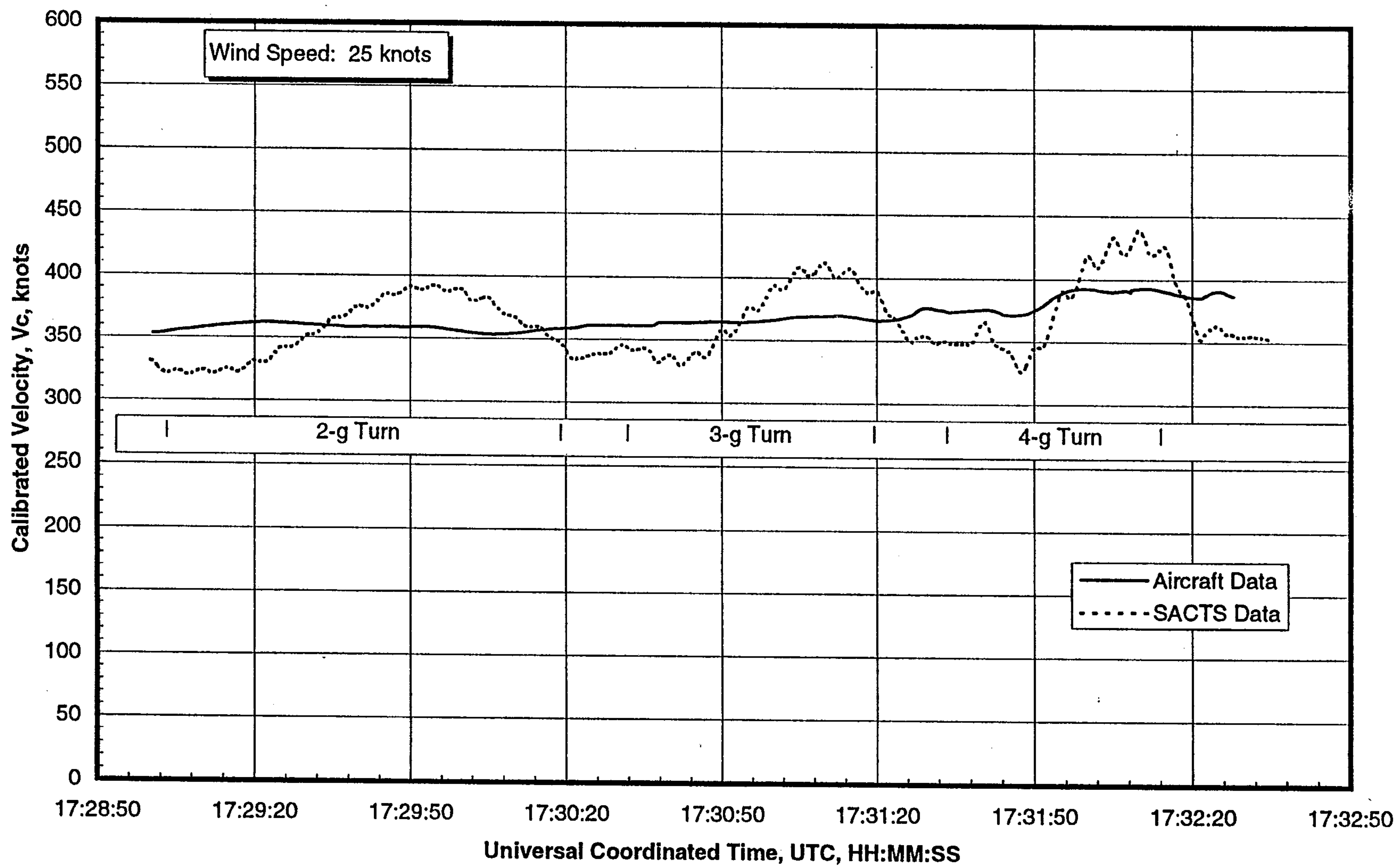

Figure B17 Velocity Correlation During Level Turns In Presence Of Winds

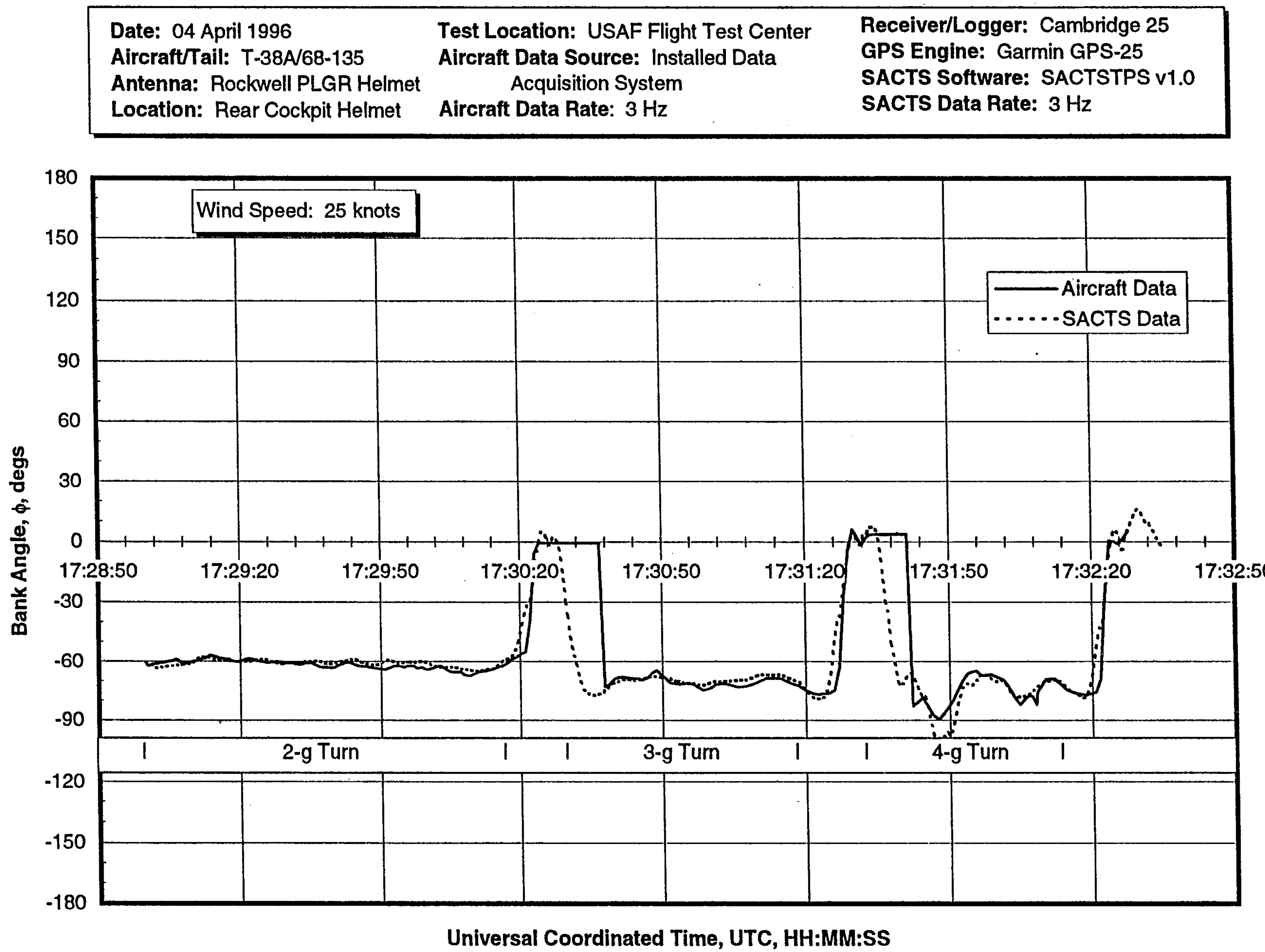

Figure B18 Bank Angle Correlation During Level Turns In Presence Of Winds

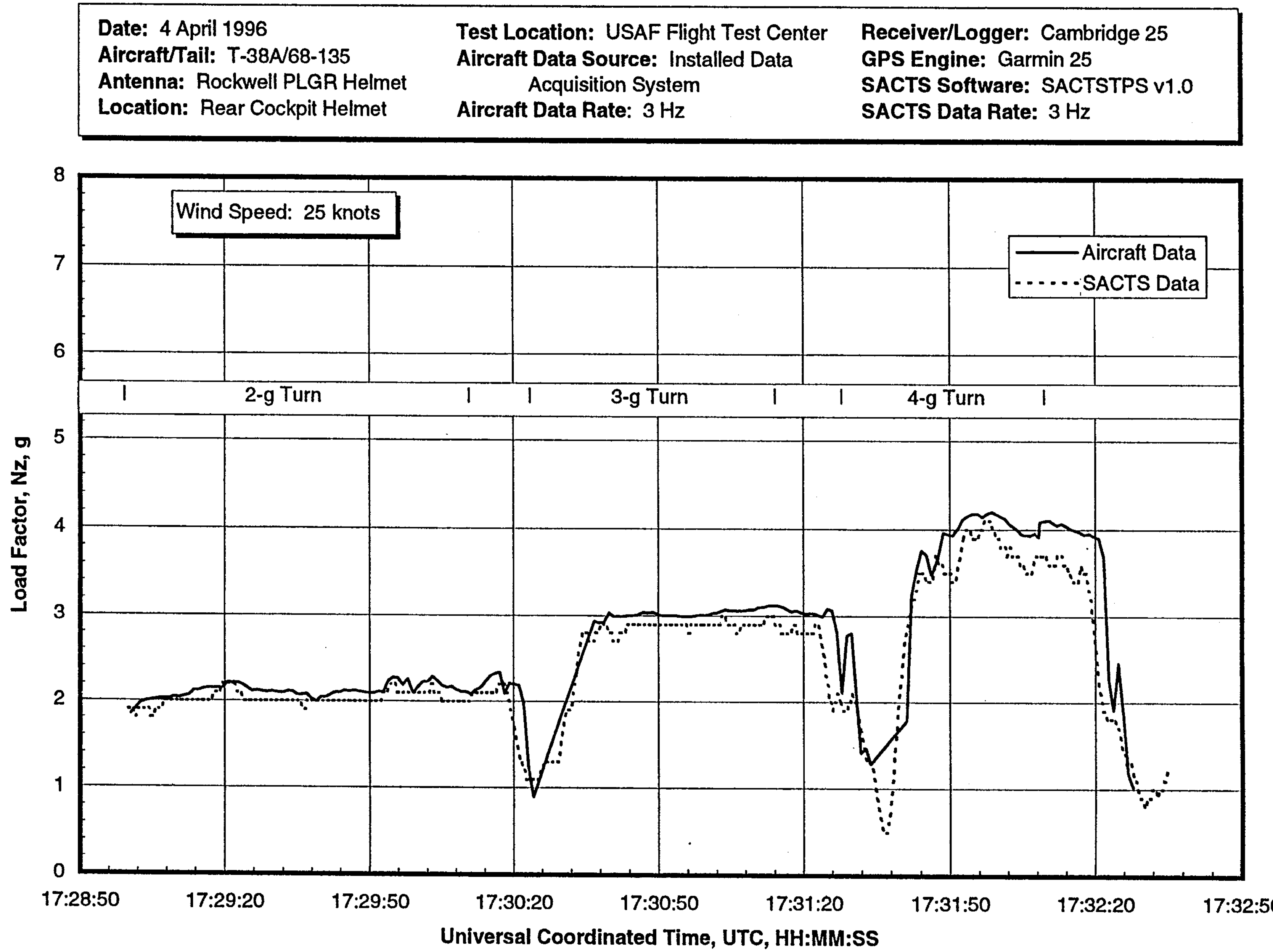

Figure B19 Load Factor Correlation During Level Turns In Presence Of Winds

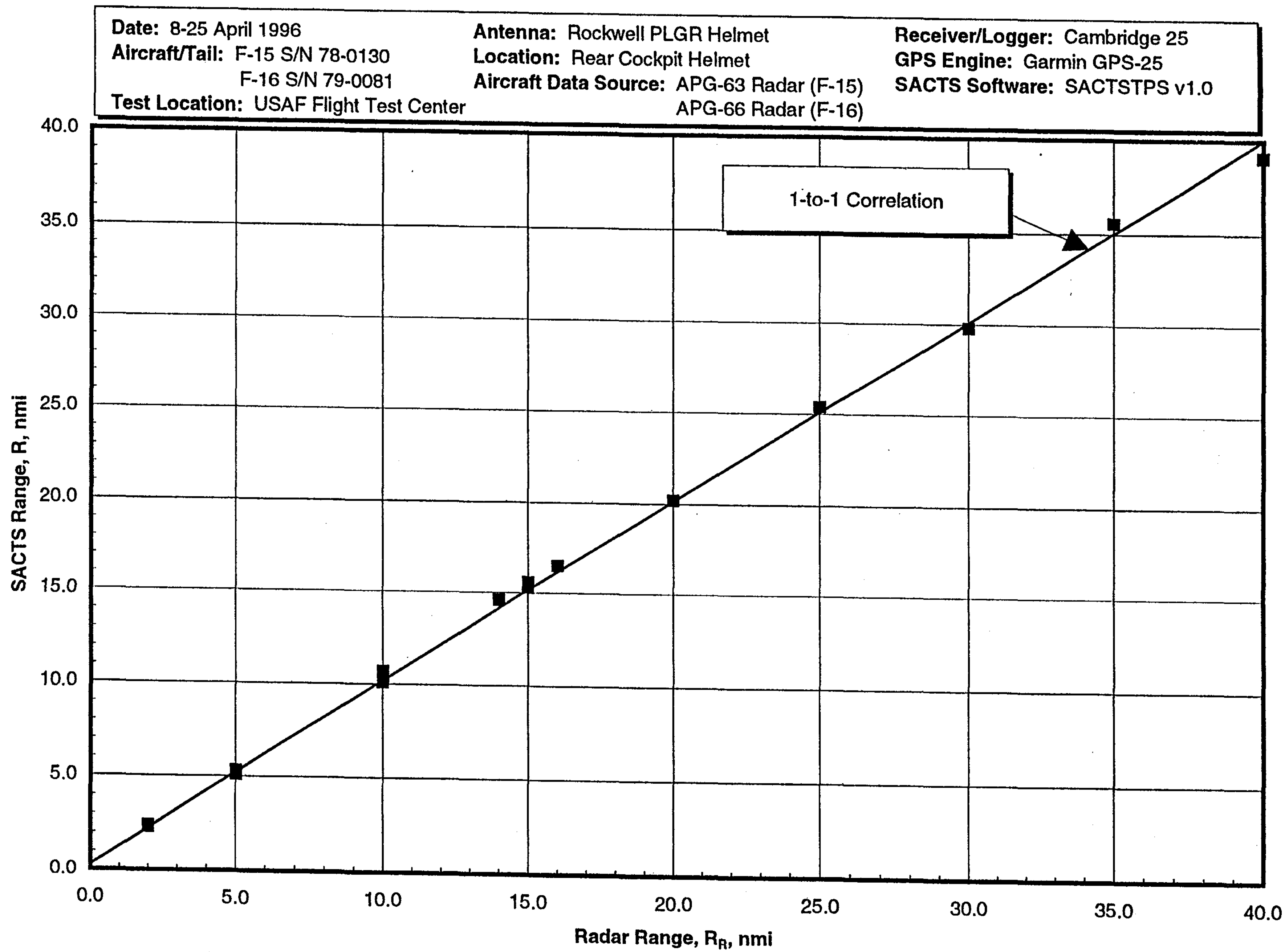

Figure B20 Range Correlation - Beyond Visual Range

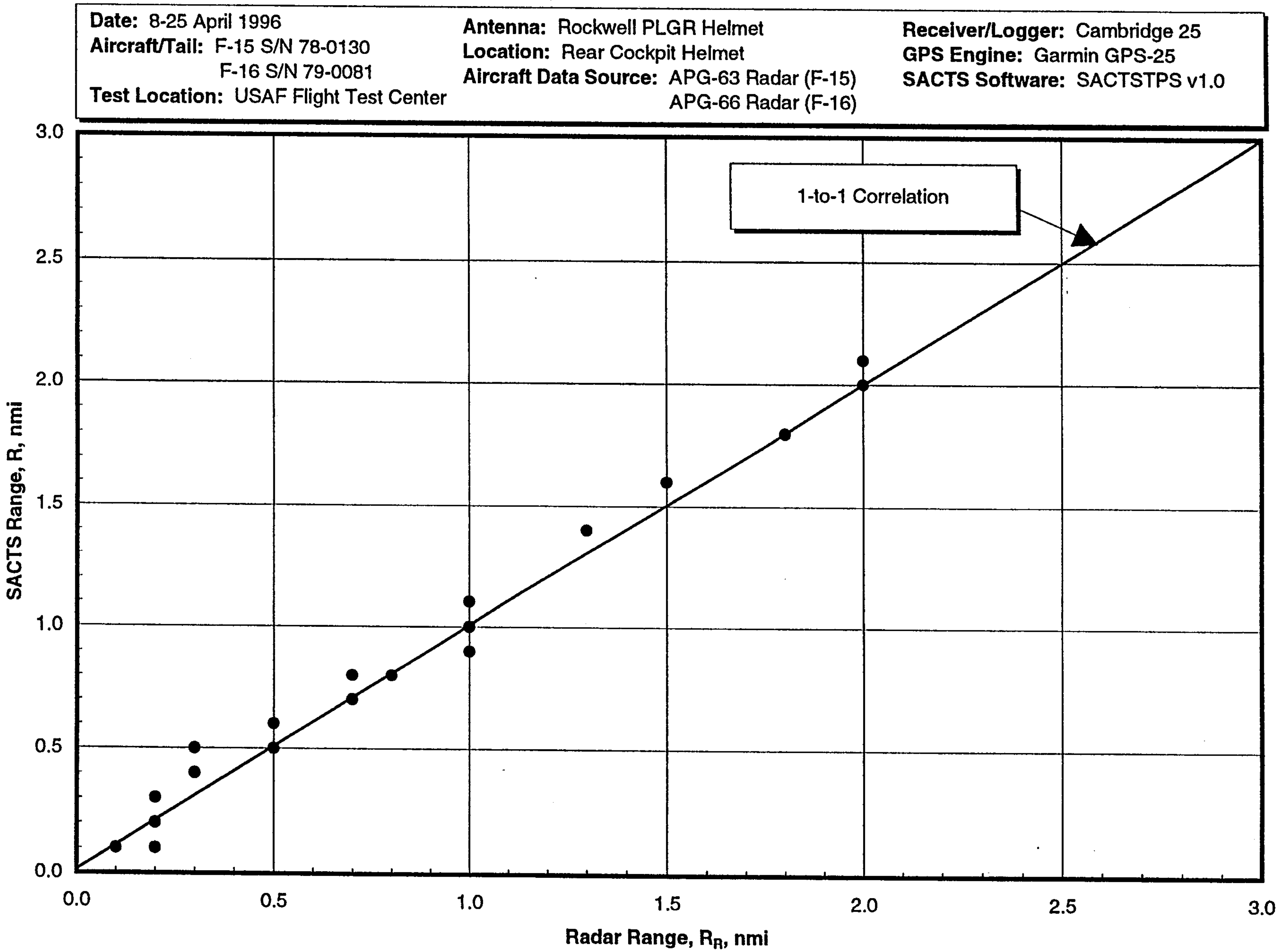

Figure B21 Range Correlation - Within Visual Range

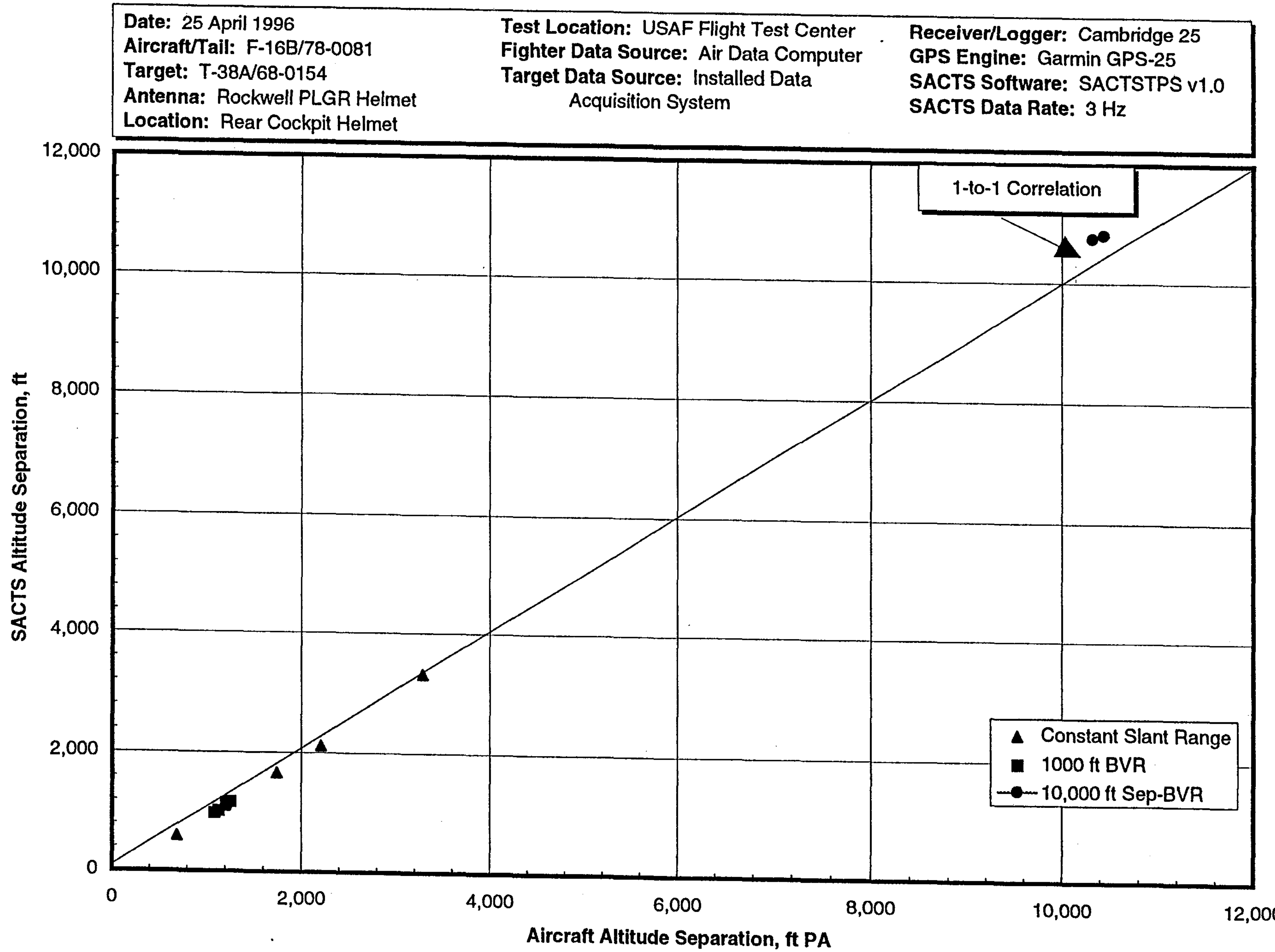

Figure B22 Altitude Separation Correlation

APPENDIX C

AIRCREW EVALUATIONS

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PERFORMANCE SECTION

The first set of ten questions are intended to provide the test team with useful indications to assess the capability of the system to achieve some outcome or perform some function related to the mission. The questions have been termed "Performance Questions." You will be asked to rate some aspects of the system using a particular rating scale (see Table I); in some cases, you will be also asked to explain the reason for a particular rating. Included in this section are questions concerning "situational awareness." The definition of "situational awareness" that will be used for this evaluation is a continuous understanding of your own aircraft's state in relation to the dynamic environment of flight, threat and mission and the ability to easily recognize portions of the flown mission.

1) Considering the ACVAT display of the engagement, your perception of relative aircraft position was (using the rating scale of Table I):

a) Beyond Visual Range Engagement:

Evaluator	Rating	Comments
Evaluation Pilot	3	Display only: worked well BVR except inability to go to the desired time. The hardware needs to handle more aggressive maneuvering to be useful. Need to add Vc (closure speed) in the software.
Project Pilot 1	3	-
Project Pilot 2	3	Tight maneuvers are not always represented as flown. The software or hardware induces some errors.
Project FTE 1	2	-
Project FTE 2	2	-

b) Within Visual Range Engagement:

Evaluator	Rating	Comments
Evaluation Pilot	6	Need not to display Vc that is wrong due to the winds. It is not a "true" display for BFM, since angles are influenced by the winds, but it is still useful.
Project Pilot 1	6	-
Project Pilot 2	4	Tight maneuvers are not always represented as flown. The software or hardware induces some errors.
Project FTE 1	5	-
Project FTE 2	4	-

2) Considering the ACVAT display of the engagement, your comprehension of relative aircraft position was (using the rating scale of Table I):

a) Beyond Visual Range Engagement:

Evaluator	Rating	Comments
Evaluation Pilot	3	Same as question 1
Project Pilot 1	2	-
Project Pilot 2	3	Same as question 1
Project FTE 1	2	-
Project FTE 2	2	-

b) Within Visual Range Engagement:

Evaluator	Rating	Comments
Evaluation Pilot	6	Same as question 1
Project Pilot 1	6	-
Project Pilot 2	4	Same as question 1
Project FTE 1	5	-
Project FTE 2	4	-

3) How would you rate the ACVAT display clarity in representing threats ?

Evaluator	Rating	Comments
Evaluation Pilot	4	Need a data button which will call up a menu to allow data to be displayed from any two aircraft. The loss of ATA (Antenna Train Angle) information outside 45 deg of the nose is unacceptable.
Project Pilot 1	3	-
Project Pilot 2	3	-
Project FTE 1	2	-
Project FTE 2	2	-

4) Considering the ACVAT HUD display capability, how would you rate its ability to provide the user with accurate visual cues of the actual state of the engagement ?

Evaluator	Rating	Comments
Evaluation Pilot	5	-
Project Pilot 1	3	-
Project Pilot 2	2	But the user has to be aware of the 2 x 45 deg representation on the screen.
Project FTE 1	3	-
Project FTE 2	3	-

5) How would you rate the ACVAT HUD display aerodynamic parameters accuracy and their usefulness in improving users' comprehension of the engagement ?

a) Beyond Visual Range Engagement:

Evaluator	Rating	Comments
Evaluation Pilot	2	Worked fine, but not really needed.
Project Pilot 1	3	-
Project Pilot 2	2	Only range is very important.
Project FTE 1	4	-
Project FTE 2	2	-

b) Within Visual Range Engagement:

Evaluator	Rating	Comments
Evaluation Pilot	5	Angular computation is worrisome, since winds are assumed to be zero. Otherwise the display is fine.
Project Pilot 1	5	-
Project Pilot 2	4	Big errors are induced due to wind. Biggest problem is the hardware losing GPS-lock.
Project FTE 1	6	-
Project FTE 2	4	-

6) How would you rate the ACVAT HUD aerodynamic and performance parameters set displayed ? Are they sufficient for a critical review of how the engagements were performed ? If not which other parameter would you like to have available ?

Evaluator	Rating	Comments
Evaluation Pilot	2	Need Vc (closure information).
Project Pilot 1	2	-
Project Pilot 2	3	16 Parameters is too much. Range, airspeed, altitude, Vc, and ATA are important.
Project FTE 1	2	-
Project FTE 2	3	Closure speed.

7) With reference to the used rating scale how would you estimate the impact of the following options on the ACVAT effectiveness in presenting a clear unambiguous picture of the engagement scenario ?

Item	Ratings	Comments
Trajectory Trails	2-4-1-2-2	Not too long. Only a trail corresponding to 10 sec of flight should do.
Ground Traces	2-3-4-2-2	Not always used. Clutters the display sometimes.
Aircraft Shapes	2-3-2-2-3	Polish item: have F-15's look like F-15's, etc...
Aircraft Sizes	2-3-2-2-3	-
Aircraft Colors	4-3-2-3-2	Need more than just 2 color options. Large packages may require 4 colors. Blue is hard to see.
Aircraft Lights (color monitor)	2-3-3-2-2	Lights are useful, but should be smaller. Some preferred to turn them off.
Range of Grid Sizes	3-2-3-2-2	Lost the grids sometimes. You can fly off the earth, and can't get the grid back. They were not intuitive to use. Provide a ruler.
Eye Azimuth Selection	4-2-2-2-3	Need one button to reset both azimuth and elevation. Additionally, the system should not allow me to adjust azimuth to the point where you go "upside down" on the display.
Eye elevation Selection	3-3-2-3-2	Same remarks as above: no need to go underground. Include an altitude scale.
Eye Origin Center Selection (ALL selected)	2-4-3-3-3	Choosing the origin is not intuitive, not user friendly. "ALL" should be the default mode.

8) How would you rate the ACVAT plotting function contribution to the student understanding of the reviewed engagement ?

Evaluator	Rating	Comments
Evaluation Pilot	-	Not used
Project Pilot 1	5	-
Project Pilot 2	2	Good and useful if it is true (i.e. no GPS break locks, little wind)
Project FTE 1	1	But not necessary
Project FTE 2	1	Operationally it wouldn't almost ever be used.

The following two questions are intended to estimate users estimate of the feasibility of future potential enhancement of the ACVAT software capabilities.

9) How would you rate the ACVAT bursts / kill capability ? Does the representation provide you with sufficient clues to accurately reconstruct the event ?

Evaluator	Rating	Comments
Evaluation Pilot	-	Not used, but a shot-down aircraft should be tagged on the display
Project Pilot 1	6	-
Project Pilot 2	5	Too much time consuming. I won't use it.
Project FTE 1	-	N/A
Project FTE 2	2	Yes, once you set time correlation between the ACVAT file and your source of information.

10) How would you consider and rate the eventual implementation of a sensor capability in the ACVAT software? The software would display threats only when the sensor model predicts the ability to see them.

Evaluator	Rating	Comments
Evaluation Pilot	6	Not for training. It has no use.
Project Pilot 1	6	-
Project Pilot 2	6	Useless gadget.
Project FTE 1	6	Probably wouldn't trust it. Don't implement.
Project FTE 2	2	Useful for prediction and simulation, rather than for post-mission reconstruction.

Table I
RATING SCALE

Descriptive Adjective	Mission Impact	Rating
Very Satisfactory	Meets or exceeds all mission requirements	1
Satisfactory	Meets all mission requirements	2
Marginally Satisfactory	Meets mission requirements with some concern	3
Marginally Unsatisfactory	Minor deficiencies some mission restriction	4
Unsatisfactory	Major deficiencies seriously degrades mission	5
Very Unsatisfactory	Major deficiencies Unusable	6

HUMAN FACTORS SECTION

The second portion of the questionnaire consists of a set of 10 questions focused on the ACVAT software ease of use or friendliness. These questions are intended to provide the test team with a useful tool to evaluate the pilot's mental and temporal demands when operating the system. The stress is on the demands imposed on the pilot and the interactions of the subject with the task. In order to identify the detrimental or beneficial features the questions are also specifically related to the functions of the software. Use the same rating scale as in the previous section (Table I) unless another is provided for you.

1) How would you rate your knowledge of computers and familiarity with MS-DOS or WINDOWS driven software (use the following scale):

1	2	3	4	5	6
None or extremely limited	Very limited Need of clear comprehensive and detailed instructions to accomplish the task	Limited tasks accomplished by use of quick reference guide	Sufficient familiarity with most popular software logic and grammar Main tasks accomplished without help	Good familiarity Generally able to accomplish all the tasks counting on the intuition	Excellent familiarity with software in general Professional knowledge

Evaluator	Rating
Evaluation Pilot	5
Project Pilot 1	5
Project Pilot 2	5
Project FTE 1	5
Project FTE 2	4

2) How would you rate the friendliness of use of the system related to its WINDOWS driven structure ?

Evaluator	Rating	Comments
Evaluation Pilot	3	-
Project Pilot 1	4	-
Project Pilot 2	2	Not all steps are intuitive. It needs some polishing.
Project FTE 1	3	Need to provide a method for getting out of the system: <ESC> or <QUIT>
Project FTE 2	2	-

3) How would you rate the mouse driven capability of the ACVAT software ?

Evaluator	Rating	Comments
Evaluation Pilot	2	-
Project Pilot 1	4	-
Project Pilot 2	2	Red mouse pointer is difficult to see. Change its color.
Project FTE 1	3	-
Project FTE 2	2	Provided some commands are made more intuitive to use.

4) How would you rate the improvement to your performance and to your ability to understand and learn the operation of the system due to the "windows" organization and mouse operation as opposed to keyboard operation (use the following scale)?

1	2	3	4	5	6
Extremely useful Necessary	Extensive improvement	Marked improvement	Sensible improvement	Negligible improvement	No improvement

Evaluator	Rating	Comments
Evaluation Pilot	2	-
Project Pilot 1	1	-
Project Pilot 2	2	Mouse/buttons especially useful if system not used very often
Project FTE 1	3	-
Project FTE 2	3	-

5. How would you rate in the following six level scale ?

1	2	3	4	5	6
Very low	Low	Moderately low	Moderately high	High	Extremely high

a) mental demand:

Evaluator	Rating	Comments
Evaluation Pilot	3	-
Project Pilot 1	3	-
Project Pilot 2	3	-
Project FTE 1	2	-
Project FTE 2	2	-

b) temporal demand:

Evaluator	Rating	Comments
Evaluation Pilot	4	Download / processing time too long.
Project Pilot 1	3	-
Project Pilot 2	5	Preparation time too long.
Project FTE 1	5	Processing time too long.
Project FTE 2	3	-

c) effort:

Evaluator	Rating	Comments
Evaluation Pilot	3	-
Project Pilot 1	3	-
Project Pilot 2	5	Due to the time you need for it.
Project FTE 1	2	-
Project FTE 2	3	-

d) frustration:

Evaluator	Rating	Comments
Evaluation Pilot	3	-
Project Pilot 1	5	-
Project Pilot 2	4	Due to the required time
Project FTE 1	2	-
Project FTE 2	4	Due to 2 or 3 software pitfalls.

6) Which improvements or changes would you suggest (list up to three of them) and rate the impact they would have on system usability and consequently your performance ? (use the following scale)

1	2	3	4	5	6
Vital improvement	Significant improvement	Moderate improvement	Slight improvement	Sensible improvement	Negligible improvement

Evaluator	Rating	Comments
Evaluation Pilot	1 1 2 2	1. Needs reset functions. 2. Must be able to "GO TO" a clock time. 3. Make the controls directly mimic VCR operations. 4. Add altitude information in the God's-eye view.
Project Pilot 1	3 3 4	1. Change play functions to more intuitive operations. 2. Allow reverse play all the way to the beginning. 3. Adjust length of the trails.
Project Pilot 2	1 2 2	1. Be able to go directly to any point in time. 2. Post flight processing should be easier and take less than 15 minutes. 3. Have a "standard display" button, which arranges the display to preset preferences.
Project FTE 1	1 2 2	1. Make the MET (Mission Elapsed Time) clock a UTC clock. 2. Make play buttons behave like VCR. 3. Include a button to return to real running time.
Project FTE 2	1 1 1	1. Include capability to go to a specific time. 2. Reset button to preset/optimized God's-eye & lateral views. 3. Higher aspect angle limit (at least 70 deg) and closure speed.

7) How would you consider your learning curve in operating the software during this session?

Evaluator	Rating	Comments
Evaluation Pilot	Steep	Relatively intuitive
Project Pilot 1	Good	-
Project Pilot 2	Steep	Most of the standard operations can be learned in less than 1 hour.
Project FTE 1	Steep	-
Project FTE 2	Sufficiently steep	1.5 Hours of familiarization are more than enough.

8) How would you consider your ability to operate the system relying on the short checklist "step by step" provided with the system ?

Evaluator	Rating	Comments
Evaluation Pilot	Not used	However, use was not a problem after 15 minutes of instruction.
Project Pilot 1	Good	-
Project Pilot 2	2	Some names are not intuitive (i.e. OTW, ...)
Project FTE 1	2	-
Project FTE 2	2	It is sufficient to playback the mission.

The last three questions are intended to directly address the issue of the system feasibility and suitability for operational employment.

1) Did the ACVAT software give your Air Combat Maneuvering mission a better training value ?
Did you learn more out of the same flight than you would have without the visual aid provided by the software ?

Evaluator	Answer	Comments
Evaluation Pilot	-	Had the system not broken lock, than it would have been great compared with ACMI (with some minor software improvements).
Project Pilot 1	Somewhat	Dropouts detracted from overall value.
Project Pilot 2	No	"NO" for its current performance (looses lock). With no GPS break locks, it would be good to debrief missions bigger than a 1 volts 1. Currently it is good for use in "Force Packages" (Fighter-bombers intercepted by fighters).
Project FTE 1	-	-
Project FTE 2	Yes	The only problem being the reliability of data when signal quality degraded.

2) If this system was available in your operational squadron, would you use it and /or recommend its use to others ?

Evaluator	Answer	Comments
Evaluation Pilot	No	I would use it if the break lock issues were solved.
Project Pilot 1	No	Not in present form. It takes too long to process the flight.
Project Pilot 2	No	Due to: current hardware problems, too long processing, and inability to go to a specific point in time during the debrief.
Project FTE 1	-	-
Project FTE 2	No	But: Yes, after the hardware problems and the main software pitfalls were fixed.

3) Evaluation pilot's main comments on the ACVAT software:

a) Processing time too long (~ 20 minutes for a 2-ship). This is the maximum time that is acceptable (40 minutes for a 4-ship is unsatisfactory).
b) Change "CNTR" step to "GODSEYE" and "OTW" step to "COCKPIT".
c) Need a one button to REAL TIME -> incorporate a pull-down menu for the functions.
d) Need a button to level the TILT and one for NORTH UP. Incorporate above menu plan for TILT and SPIN.
e) STOP as a reset is bad. Make the functions operate exactly like a VCR if they look like a VCR.
f) Need to be able to enter a TIME and go directly to that time in ACTUAL TIME or ELAPSED TIME.

g) Need to be able to call up the data screen in God's-eye view.
h) Don't display incorrect data (example: KCAS). Add Vc (closure speed).
i) Rewind function is limited. Not bad if GO TO TIME function would be added.
j) Fix the ATA limit. Default the data to the 2 nearest bandits with option to view data between any two aircraft.
k) SHOW STOPPER ! Unsatisfactory if the systems breaks lock during hard maneuvering.

OVERALL: Good concept. I really think you need to read the data from the aircraft's data bus.

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APPENDIX D

TEST POINT SUMMARY

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Table D1
TEST POINT SUMMARY

MSN	Date	A/C	Tail	A/C ID	Crew	Duration	Maneuvers Flown
1	4 April	T-38	63-8135	1	Prosser/Lolli	1.2	Aircraft blanking and operational maneuvers
2	4 April	T-38	63-8135	1	Vaerten/Dickey	1.0	Aircraft blanking and operational maneuvers
3	8 April	F-15	76-0130	1	Prosser/Dickey	1.3	Relative range and altitude Aircraft blanking and operational maneuvers
		T-38	63-8135	2	Tinkham/Lolli	1.2	Target Operational maneuvers
4	15 April	F-15	76-0130	1	Prosser/Lolli	1.5	Relative range and altitude Aircraft blanking and operational maneuvers
		T-38	63-8135	2	Vaerten/Winschel	1.2	Target Operational maneuvers
5	18 April	T-38	63-8135	1	Prosser/Lolli	1.1	Tactical formation and advanced rejoins
		T-38	68-8205	2	Vaerten/Dickey	1.0	Target/Wingman
6	22 April	T-38	68-8154	1	Vaerten/Dickey	0.9	Reacquisition tests and operational maneuvers
7	22 April	T-38	68-8205	1	Prosser/Lolli	1.1	Reacquisition tests and operational maneuvers
8	24 April	F-16	78-0098	1	Vaerten/Dickey	1.2	Noneffective GPS Battery Fail
		T-38	63-8135	2	Prosser/Lolli	0.5	Air Abort
9	25 April	F-16	78-0081	1	Vaerten/Dickey	1.7	Relative range and altitude Operational maneuvers
		T-38	68-8154	2	Prosser/Lolli	1.2	Target Operational m maneuvers Reacquisition tests
10	29 April	F-15	76-0134	1	Prosser/Lolli	1.5	BVR intercepts
		T-38	63-8135	2	Vaerten/Skeen	1.2	Target
11	1 May	F-15	76-0134	1	Brewer/Elkin	1.1	BVR intercepts Advanced rejoins
		T-38	68-8154	2	Prosser/Dickey	0.9	Target

Notes: 1. MSN - mission
2. A/C - aircraft
3. ID - identification
4. GPS - global positioning system
5. BVR - beyond visual range

Table D2
PHASE I FUSELAGE BLANKING TESTS

Aircraft Attitude 15,000 ft ±5,000 ft, 350 kt ±50 kt, Hold 5 to 10 sec		
Test Point	Pitch (deg)	Roll (deg)
1a	0	0
1b	0	45
1c	0	90
1d	0	135
1e	0	180
1f	45	0
1g	90	0
1h	45	180
1i	45	45
1j	45	90

Table D3
PHASE I REACQUISITION TESTS

Aircraft Parameters 15,000 ft, ±5,000 ft, ±10 KIAS		
Test Point	Airspeed (KIAS)	Maneuver
1k	250	NONE
1l	350	NONE
1m	450	NONE
1n	250	90-deg turn
1o	350	90-deg turn
1p	450	90-deg turn
1q	250	acceleration to 450 kt
1r	250	descend 20,000 ft (start above 25,000 ft)
1s	250	90-deg turn descend 20,000 ft (start above 25,000 ft)

Table D4
PHASE II OPERATIONAL MANEUVER ACCURACY

Test Point	Maneuver (Data Band Tolerance: ±5,000 ft, ±50 KIAS, ±0.2 g)
2a	0-g Aileron roll: 15,000 ft, 350 KIAS, 60-deg/sec roll rate (±20 deg/sec)
2b	2-g Barrel roll: 15,000 ft, 350 KIAS, 60-deg/sec roll rate, 20 deg heading envelope (±5 deg)
2c	2-,3-,4-,5-,6-g MIL power turns 350-400 KIAS
2d	Loop: 15,000 ft, 500 KIAS, 4-g initial pull
2e	Cloverleaf: 15,000 ft, 500 KIAS, 4-g initial pull
2f	Break to slice: 350 KIAS, 20,000 ft, 4-g level turn for 90 deg, immediate reverse to a 135-deg slice for 180 deg of turn
2g	Post hole: 300 KIAS, 20,000 ft, 4-g 360-deg turn while descending 10,000 ft
2h	Notch, 350 KIAS, 20,000 ft, 4-g 90-deg turn, delay 4 sec then 90-deg turn in opposite direction. Complete with 10,000 ft altitude loss
2i	Level Notch: 4 level 90-deg turns alternating directions with 2-sec delay between turns
2j	Roller Coaster: 300 kt, 20,000 ft, 0.5-g pushover to 45-deg nose low, acceleration to 450 KIAS, 4-g pull to 45-deg nose high at 15,000 ft, recover with 0.5-g pushover to level flight at 20,000 ft 300 KIAS

Table D5
PHASE III RELATIVE RANGE AND ALTITUDE ACCURACY

Test Point	Target	Aspect (deg)	Data Collected At: Ranges (ft)
4a	1-g wings level	0	500, 1,000, 1,500, 2,000, 3,000, 4,000,5,000, 6,000, 9,000, 12,000
4b	1-g wings level	30	500, 1,000, 1,500, 2,000, 3,000, 4,000,5,000, 6,000, 9,000, 12,000
4c	1-g wings level	60	500, 1,000, 1,500, 2,000, 3,000, 4,000,5,000, 6,000, 9,000, 12,000
4d	3-g, level turn	30	500, 1,000, 1,500, 2,000, 3,000, 4,000,5,000, 6,000, 9,000, 12,000
4e	5-g, MAX turn hold Alt	60	500, 1,000, 1,500, 2,000, 3,000, 4,000
4f	1-g wings level	0, 11,000 ft slant range	500, 1,000, 1,500, 2,000, 3,000, 4,000, 5,000, 6,000 ft vertical offset high
4g	1-g level, 15,000 ft	180, 40 nm, 16,000 ft	40 nm, 35 nm, 30 nm, 25 nm, 20 nm, 15 nm, 10 nm, 5 nm, 2 nm
4h	1-g level, 15,000 ft	180, 40 nm, 25,000'	40 nm, 35 nm, 30 nm, 25 nm, 20 nm, 15 nm, 10 nm, 5 nm, 2 nm

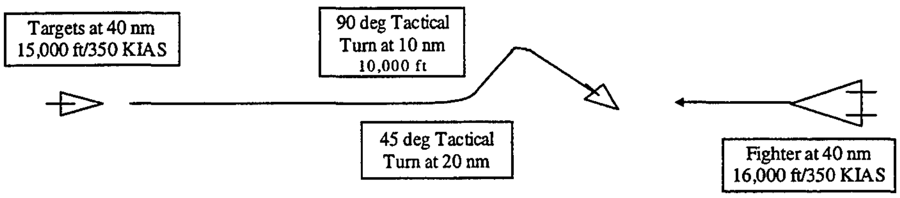

Figure D1 BVR Intercept 1

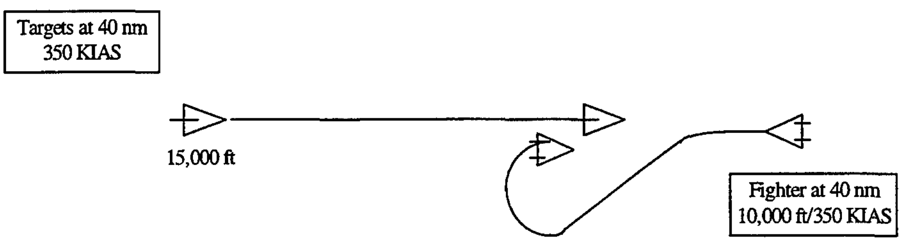

Figure D2 BVR Intercept 2

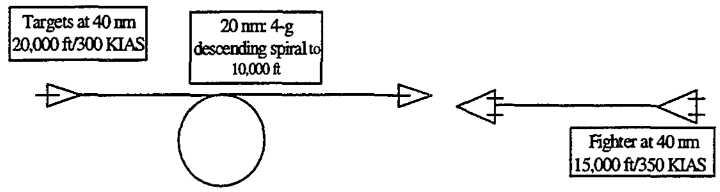

Figure D3 BVR Intercept 3

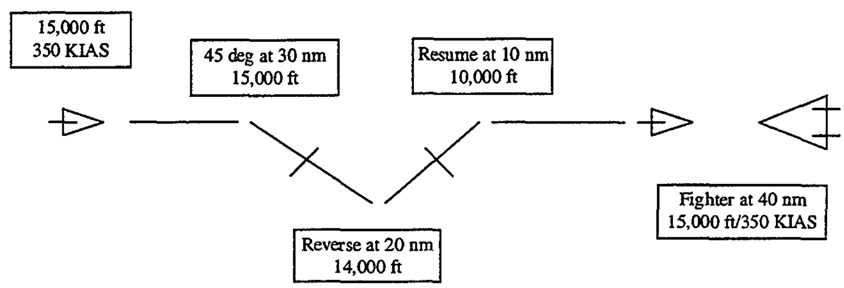

Figure D4 BVR Intercept 4

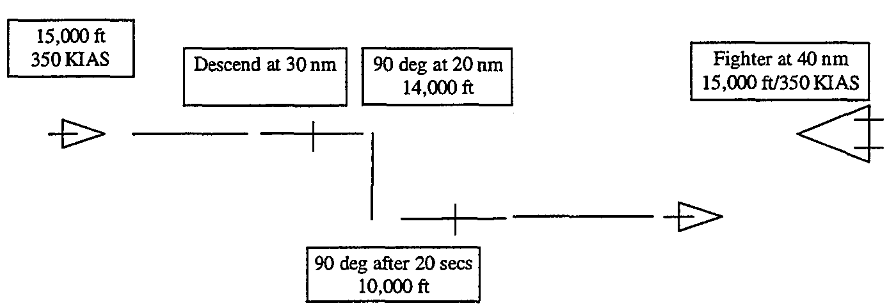

Figure D5 BVR Intercept 5

APPENDIX E

INSTRUMENTATION PARAMETERS

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Table E1
T-38 DAS PARAMETERS

Parameter Name	Source	Range	Resolution	Approximate Measurement Uncertainty	Samples (per sec)
Right Engine Fuel Flow	Transducer	0.5 to 10 gpm	0.01 gpm	0.05 gpm	4
Right After Burner Fuel Flow	Transducer	15 to 25 gpm	0.01 gpm	0.05 gpm	4
Right Fuel Used	Transducer - 20 BIT	0 to 2,000 gal	0.01 gal	0.5 gal	4
Left Engine Fuel Flow	Transducer	0.5 to 10 gpm	0.01 gpm	0.05 gpm	4
Left After Burner Fuel Flow	Transducer	15 to 25 gpm	0.01 gpm	0.05 gpm	4
Left Fuel Used	Transducer - 20 BIT	0 to 2,000 gal	0.01 gal	0.5 gal	4
Event Counter	Transducer	0 to 99 Count	Discrete	N/A	4
Event Marker	Transducer	0 or 1	Discrete	N/A	32
Longitudinal Stick Force	Transducer	±70 lb	0.17 lb	0.85 lb	32
Lateral Stick Force	Transducer	±35 lb	0.08 lb	0.5 lb	32
Left Rudder Pedal Force	Transducer	0 to -150 lb	0.15 lb	0.75 lb	32
Right Rudder Pedal Force	Transducer	0 to 150 lb	0.15 lb	0.75 lb	32
θ - Pitch Angle	Transducer	±80 deg	0.06 deg	0.3 deg	32
ϕ - Roll Angle	Transducer	±175 deg	0.35 deg	1.75 deg	32
p - Roll Rate	Transducer	±360 deg/sec	0.7 deg/sec	3.5 deg/sec	32
q - Pitch Rate	Transducer	±20 deg/sec	0.05 deg/sec	0.25 deg/sec	32
r - Yaw Rate	Transducer	±20 deg/sec	0.05 deg/sec	0.25 deg/sec	32
Total Pressure	Transducer	0.4 to 38 psia	0.04 psia	0.2 psia	32
Static Pressure	Transducer	0.4 to 38 psia	0.04 psia	0.2 psia	32
Right Engine rpm	Transducer	25 to 102 pct rpm	0.15 pct	0.75 pct	32
Left Engine rpm	Transducer	25 to 102 pct rpm	0.15 pct	0.75 pct	32
α - Angle of Attack	Transducer	-10 to 30 deg	0.04 deg	0.2 deg	32
β- Angle of Sideslip	Transducer	±20 deg	0.04 deg	0.2 deg	32
Right Engine Fuel Temp	Transducer	-50 to 150 deg C	0.3 deg C	1.5 deg C	32
Left Engine Fuel Temp	Transducer	-50 to 150 deg C	0.3 deg C	1.5 deg C	32
Outside Air Temp	Transducer	-55 to 85 deg C	0.2 deg C	1 deg C	32
Normal Acceleration	Transducer	-3 to 6 g	0.01 g	0.05 g	32
Lateral Acceleration	Transducer	±1 g	0.002 g	0.01 g	32
Longitudinal Acceleration	Transducer	±1 g	0.002 g	0.01 g	
Longitudinal Stick Position	Transducer	-4 to 7 in	0.02 in	0.1 in	32
Lateral Stick Position	Transducer	±8 in	0.02 in	0.1 in	32
Rudder Pedal Position	Transducer	±3 in	0.01 in	0.05 in	32
Stabilator Position	Transducer	-6 to 16 deg	0.03 deg	0.15 deg	32
Right Aileron Position	Transducer	-25 to 35 deg	0.08 deg	0.4 deg	32
Left Aileron Position	Transducer	-35 to 25 deg	0.08 deg	0.4 deg	32
Rudder Position	Transducer	±30 deg	0.07 deg	0.35 deg	32
IRIG Time	---	---	---	---	32
Hot Mike	---	---	---	---	---

Notes:
1. DAS - data acquisition system
2. N/A - not applicable
3. Temp - temperature
4. BIT - built-in-test
5. psia - pounds per square inch absolute
6. IRIG - Inter-Range Instrumentation Group
7. '---' - not applicable

Table E2
F-15 ATIS PARAMETERS

Parameter Name	Source	Range	Resolution	Approximate Measurement Uncertainty	Samples (per sec)
Left Aileron Position	Transducer	±20 deg	0.05 deg	0.25 deg	53.33
Right Aileron Position	Transducer	±20 deg	0.05 deg	0.25 deg	53.33
Left Stabilator Position	Bus - 16 BIT	- 30 to 15 deg	0.006 deg	0.03 deg	26.66
Right Stabilator Position	Bus - 16 BIT	- 15 to 30 deg	0.006 deg	0.03 deg	26.66
Left Rudder Position	Transducer	±30 deg	0.04 deg	0.2 deg	53.33
Right Rudder Position	Transducer	±30 deg	0.04 deg	0.2 deg	53.33
Speed Brake Position	Transducer	0 to 45 deg	0.03 deg	0.15 deg	53.33
Longitudinal Stick Force	Transducer	±25 lb	0.04 lb	0.2 lb	53.33
Lateral Stick Force	Transducer	±20 lb	0.05 lb	0.25 lb	53.33
Longitudinal Stick Position	Transducer	-3 to 6 in	0.008 in	0.04 in	53.33
Lateral Stick Position	Transducer	±4 in	0.007 in	0.035 in	53.33
Right Rudder Pedal Force	Transducer	±200 lb	0.3 lb	1.5 lb	53.33
Left Rudder Pedal Force	Transducer	±200 lb	0.3 lb	1.5 lb	53.33
Right Rudder Pedal Position	Transducer	±4 in	0.02 in	0.1 in	53.33
Left Rudder Pedal Position	Transducer	±4 in	0.02 in	0.1 in	53.33
Right Power Lever Angle	Transducer	0 to 130 deg	0.09 deg	0.45 deg	6.66
Left Power Lever Angle	Transducer	0 to 130 deg	0.09 deg	0.45 deg	6.66
Left Fuel Flow	Transducer	0 to 100,000 lb/hr	0.025 lb/hr	1.25 lb/hr	6.66
Right Fuel Flow	Transducer	0 to 100,000 lb/hr	0.025 lb/hr	1.25 lb/hr	6.66
Left Engine Nozzle Area	Transducer	2.5 to 65. ft^2	0.022 ft^2	0.11 ft^2	6.66
Right Engine Nozzle Area	Transducer	2.5 to 65. ft^2	0.022 ft^2	0.11 ft^2	6.66
Left Core Speed (N2)	Production System	0 to 110 pct	0.2 pct	1.0 pct	53.33
Right Core Speed (N2)	Production System	0 to 110 pct	0.2 pct	1.0 pct	53.33
Pressure Altitude	Bus - 16 BIT	-1560 to 80,337 ft	1.25 ft	6.25 ft	26.66
ψ - Heading Angle	Bus	±180 deg	0.4 deg	2 deg	26.66
θ - Pitch Angle	Bus	±180 deg	0.09 deg	0.45 deg	26.66
ϕ - Roll Angle	Bus	±180 deg	0.09 deg	0.45 deg	26.66
Mach Number	Bus - 15 BIT	0.0985 to .0195	0.0002	0.01	26.66
V_T - True Velocity	Bus - 15 BIT	60 to 1710 kt	0.125 kt	0.635 kt	26.66
Indicated Airspeed	Bus - 15 BIT	14.12 to 999.9 kt	0.625 kt	3.2 kt	26.66
Total Fuel Quantity	Bus - 16 BIT	0 to 25,600 lb	2 lb	10 lb	26.66
p - Roll Rate	Transducer	±120 deg/sec	0.1 deg/sec	0.5 deg/sec	53.33

Table E2 (Concluded)
F-15 ATIS PARAMETERS

Parameter Name	Source	Range	Resolution	Appropriate Measurement Uncertainty	Samples (per sec)
q - Pitch Rate	Transducer	±60 deg/sec	0.1 deg/sec	0.5 deg/sec	53.33
r - Yaw Rate	Transducer	±60 deg/sec	0.1 deg/sec	0.5 deg/sec	53.33
n_z - Load Factor (Coarse)	Transducer	-10 to 10 g	0.02 g	0.1 g	53.33
n_z - Load Factor (Fine)	Transducer	±3 g	0.004 g	0.02 g	53.33
n_y - Lateral Acceleration	Transducer	±2 g	0.004 g	0.02 g	53.33
n_x - Axial Acceleration	Transducer	±2 g	0.003 g	0.015 g	53.33
Normal Acceleration	Bus - 16 BIT	±16 g	0.0005 g	0.0025 g	26.66
α - Angle of Attack - True	Bus	-5 to 35 deg	0.05 deg	0.25 deg	53.33
β- Angle of Sideslip - Fine	Transducer	±30 deg	0.025 deg	0.125 deg	53.33
Total Temp	Production	-50 to 150 deg F	0.5 deg F	2.5 deg F	53.33
Event Marker	Transducer	---	Discrete	---	53.33
IRIG Time	---	---	---	---	53.33
Voice	---	---	---	---	2,666.66

Notes: 1. ATIS - airborne test instrumentation system
2. BIT - built-in-test
3. IRIG - Inter-Range Instrumentation Group
4. '---' - not applicable

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APPENDIX F

SACTS POSTFLIGHT PROCESSOR

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SACTS POSTFLIGHT PROCESSOR

For the HAVE ACME investigation, the contractor provided a prototype version of the postflight processor (PFP) and Version 1.0 of the air combat visualization analysis tool (ACVAT) software. A flowchart of the integrated CAMBRIDGE/PFP/ACVAT software architecture used in the data reduction and processing is shown in Figure F1. This prototype software contains data reduction and analysis options that may not be included in the production version of the PFP Software, but were necessary in the prototype version to research the best methods to reduce the global positioning system (GPS) 1-hertz data-stream for fighter type aircraft in highly dynamic maneuvering flight.

The primary functions of the PFP Software were as follows:

1. To read the raw GPS data-streams provided by the SACTS receiver/recorders and convert the timed GPS position data to x/y/z data referenced to an appropriate local Earth reference. The PFP Software also sensed GPS data dropouts in the raw 1 hertz data and interpolated to fill in the data stream.
2. To numerically process the raw 1 hertz time/x/y/z data and deduce aircraft position/attitude/dynamic variables.
3. To provide for missile shot input.
4. To write the three-dimensional (3D) graphic data-file used to drive the aircraft/missile scenario replay in ACVAT.
5. The PFP prototype version of the software also wrote a plot file of a single aircraft in the scenario from which a more rigorous analysis could be conducted.

The execution of the PFP Software required the input of several parameters relating to the smoothing algorithm, aircraft aerodynamic and performance model, and finally display options. A list of the inputs required by the software follows. Actual software prompts are given in italics. The values used during the HAVE ACME test program are provided in parentheses.

- *Do you have an IFILExxx.DAT (number=xxx, 0 - no file)?*

If the user was about to process an engagement for the first time he would have input a "0." If the flight had previously been processed, he would have specified the three-digit code identifying the flight file he wanted to process.

- *INPUT THE NUMBER OF AIRCRAFT GPS FILES TO PROCESS*
  Number N of aircraft in the scenario (e.g., 2)
  Enter filename for ac *1*
  (651c4301)[2]
  Enter filename for ac *2*
  (651c3591)

- *INPUT A/C* *1* *SIDE (1- BLUE, 2-RED)*
  The side (ISIDE) of each aircraft in the scenario (1 or 2)
- *INPUT A/C* *1* *TYPE (1-FIGHTER, 2-BOMBER, 3-HELICOPTER)*
- *ACVAT CAN ESTIMATE ANGLE OF ATTACK (AOA) IF YOU PROVIDE THE FOLLOWING ENGINEERING VARIABLES ON EACH A/C*
  1-WEIGHT(LB)
  2-MAX>LIFT COEFFICIENT
  3-STALL AOA (DEGREES)
  4-AERO REFERENCE AREA(FT2)
  5-THRUST/WEIGHT RATIO

[2] File naming conventions are contained in Reference 3.

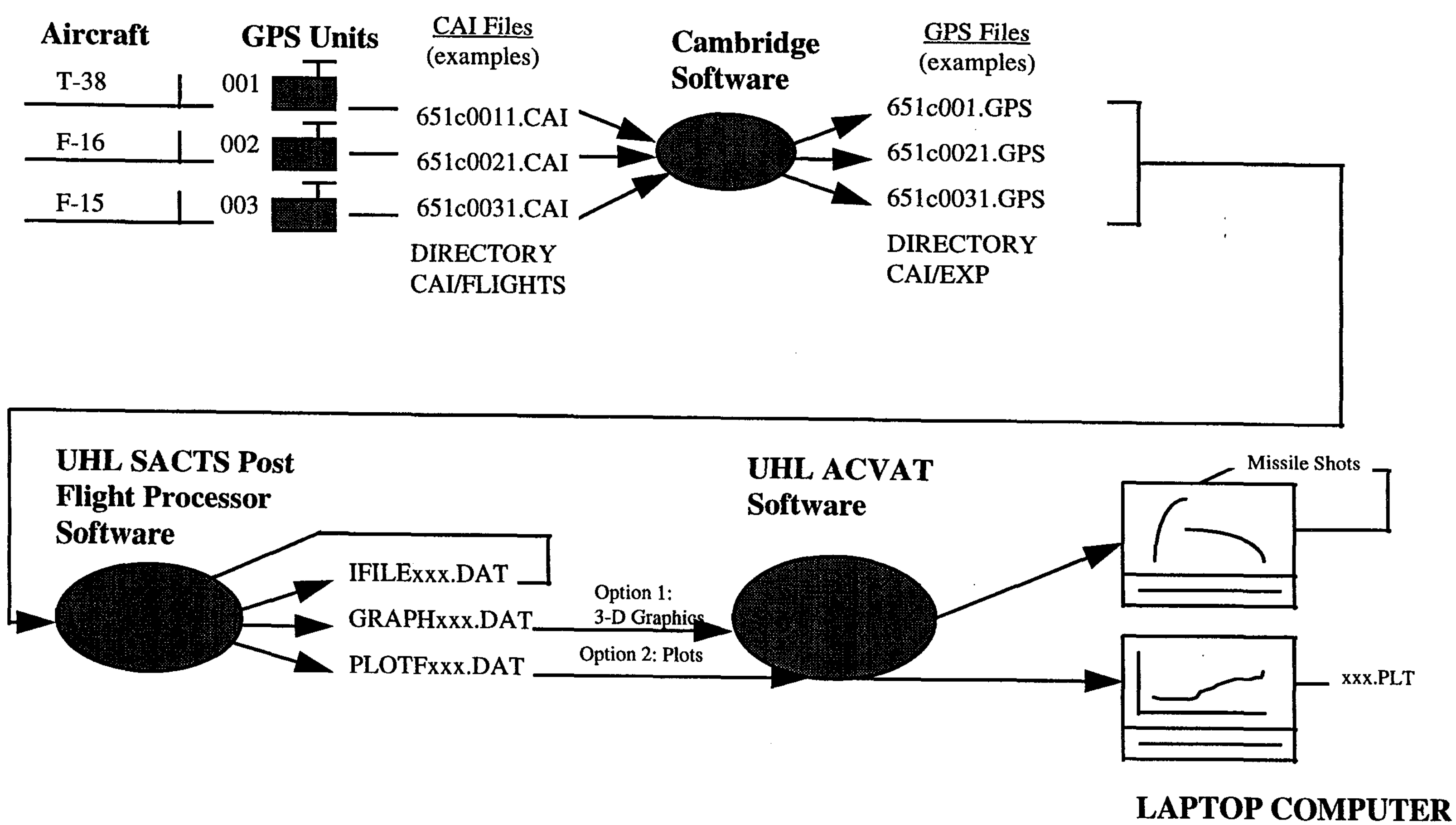

Figure F1 SACTS Software Data Reduction System/Process

DO YOU WANT TO ESTIMATE AOA (1-YES, 0-NO)
INPUT A/C 1 Weight (lb) /Clmax /Stall AOA(deg) /Aero Ref Area (ft2) / T/W Ratio
Flag to compute AOA and other aerodynamic parameters for the aircraft in the scenario (1-Yes, 2-No). This computation was based on 5 parameter-based aircraft models. The values used during the test program for each parameter are given in Table F1.
1-Average combat weight in pounds
2-Maximum lift coefficient at subsonic speeds
3-Stall AOA at subsonic speeds
4-Reference area in square feet
5-Thrust to weight ratio

Table F1
PERFORMANCE MODEL PARAMETERS USED

Aircraft Type	Combat Weight (lb)	$C_{L\,Max}$	α_{stall}	Reference Area (ft^2)	Thrust-to-Weight (T/W)
T-38	10,605	0.830	10.5	170	0.609
F-16	25,500	1.680	25.0	300	0.935
F-15	35,850	1.100	19.5	608	1.040

Notes: 1. $C_{L\,Max}$ - maximum lift coefficient
2. α_{stall} - stall angle of attack

- *INPUT THE DATA SOURCE OF ALTITUDE DATA*
  1-GPS ALTITUDE
  2-PRESSURE ALTITUDE
  Since all aircraft had pressurized cockpits, GPS altitude was used. (1)

- *INPUT THE LOCAL MAGNETIC VARIATION*
  Local magnetic variation at location of engagement (-14.5 deg)

- *INPUT NUMBER OF DATA STEPS FOR X-Y SMOOTH INTERVAL >= 5*
  Approximate time (INTV) it takes the fastest turning aircraft in the scenario to perform a 360 degree turn. For an estimated 22 degree/second of turn rate, 14 seconds are required (14)

- *INPUT NUMBER DATA STEPS > (number previously input) <=120 for Z-smoothing*
  In order to allow further smoothing on the altitude, usually more noisy data than position data on the horizontal plane, the duration of the smoothing interval was set longer than the smoothing time slice used for X-Y data.

- *INPUT THE NUMBER OF X-Y GPS SMOOTHING TRIALS*
- *INPUT THE EXTRA GPS SMOOTHING TRIALS*
  These 2 inputs were smoothing parameters that the contractor optimized upon analysis of the first flight data provided. (30)[3]

[3] Rationale in the setting of the optimizing smoothing parameters were the theoretical assumptions (validated by flight test data) that:
1- X-Y position error in the Cambridge receiver data is of the order of meters
2- Altitude Z position error is normally larger than the errors in the horizontal plane
Success of the smoothing algorithm can be proven strongly affected by first and second derivatives of the position data which resulted by themselves very noisy at first. The smoothing technique used in SACTS is characterized by a smoothing interval of time (SIT) and the number of smoothing trials (NST) tailored differently and respectively for X-Y and Z data. Both SITs and NSTs were set by experimental test with actual data; experience to date showed how the SITs are strongly affected by the maneuverability of the aircraft and end up being of the same order of magnitude of a 360 degree turn duration.

- *INPUT NUMBER FOR METHOD TO TIME-PHASE GPS FILES*
  1-TO=0 FOR ALL A/C-RELATIVE TIME PHASING
  2-START DISPLAY AT MAXIMUM TO ALL A/C
  Input the set time-phasing (IPHASE) of the N aircraft in the scenario as follows:

1-This input will cause all aircraft to start at time 0.0 regardless of the ZULU time in the N aircraft GPS data-files. This phasing mode was specifically designed for the flight test program. This would allow the user to reduce, view and test the PFP/ACVAT software with multiple aircraft using only one data file. The PFP software would artificially translate each trajectory so that they would not appear superimposed in the ACVAT scenario replay.

2-This input will time-phase all N aircraft to start at the maximum ZULU start time of all the aircraft data files used in the data reduction. This is the normal time phasing that would be used in actual operations. The PFP software will screen-print this ZULU start time and should be recorded to correlate the relative time presented in ACVAT with pilot absolute ZULU times for missile launches. (2)

- *INPUT # IFILExxx.DAT TO SAVE (#=xxx, 0=none)*
  Three-digit code identifying the input file being processed and containing all the input parameters used. (e.g. 001)

- *DO YOU WANT TO INPUT MISSILE FIRING ? (1-Yes / 0-No)*
  HOW MANY MX-SHOTS FOR AIRCRAFT 1
  GPS-NAME: (e.g.651c4301)
  SIDE : 1
  TYPE: 1
  SELECT A TARGET/NUMBER
  RED-TARGET# = 1 GPSNAME=(e.g.651c3591) TYPE=1
  SELECT MISSILE (1-IR / 2-BVR)
  INPUT SHOT ZULU HOUR /0-24 (MINUTE / 0-60)(SECOND / 0-60)
  Input missile shot flag (IFIRE) (1-Shot data, 2-No Shot data); this input was used to indicate if missile shot data were to be input; in this case the following inputs must be provided:

  a. - Number of missiles fired in the scenario (ISMX)
  b. - Threat/target aircraft number as observed in the ACVAT replay
  c. - Type of missile shot (1-Short range, 2-Long range)
  d. - Absolute ZULU hour of launch
  e. - Absolute ZULU minute of launch
  f. - Absolute ZULU seconds of launch

The previous menu would be available by default for all the aircraft involved in the scenario sequentially according to their initial numbering.

The following variables, input for the runtime of the PFP, were not saved in the IFILE:

- *INPUT THE NUMBER OF DIVISIONS OF THE GPS 1-HERTZ DATASTREAM*
  0-NONE / <= 4
  Number of division of the 1 hertz GPS data stream to fill with interpolated values; this was a smoothing technique parameter. Two divisions led to a 3 hertz data stream. (2)

- *ITMAX=(eg. 69936) IMAX=(eg. 74288) DTMAX=(eg. 4352) HMIN=(eg.1932)*
  MAX ZULU START: HR= 19 MIN= 25 SEC= 36
  MIN ZULU END: HR= 20 MIN= 38 SEC= 8

These are the start and end times of the overlapping portions of the selected files. ITMAX and IMAX represent respectively the start and end zulu times of the common portion of the flights (or the start and end times of the overlapping portions of the files associated with each aircraft flight. One day is equal to 86,400 second.

- *INPUT THE ALTITUDE FOR THE ACVAT GROUND PLANE (FT)*
  Input the altitude (ft) by which to raise (+) or to lower (-) all the aircraft in the scenario. The ground-plane in the ACVAT is at zero altitude. Note that a (-) input in effect raises the ground plane (-2290)

- *INPUT THE ACVAT GRAPHxxx.DAT NUMBER=xxx*
  Input the three digit code for the 3-D graphic display file just created (e.g. 001)

- *INPUT THE ACVAT PLOTFxxx.DAT NUMBER=xxx*
  Input the three digit code for the 3-D plot file just created (e.g. 001)

- *INPUT THE NUMBER OF SECONDS TO ANALYZE*
  Input the number of seconds to analyze with the PFP software (ISTOP); this needs to be less than the maximum screen-displayed length of the aircraft files in the scenario (this value would be displayed on the screen as output -DTMAX- prior to this step)

- *INPUT THE NUMBER OF SECONDS TO PLOT*
  Input the number of seconds to plot (usually the same as in 16) and the aircraft for which it was required.

- *INPUT THE NUMBER OF SECONDS FOR 3-D GRAPHICS*
  Input the number of seconds to display graphically (usually the same as in 16) and the aircraft for which it was required.

- *INPUT ZULU (SECONDS) WHERE PLOT FILE IS TO START*
  Input the start time in seconds at which the PFP analysis must be started (ISTART) ISTART+IGRAPH must be < ISTOP

- *INPUT NUMBER OF DATA STEPS FOR PLOT OUTPUT FREQUENCY*
- *INPUT NUMBER OF DATA STEPS FOR 3-D GRAPHICS FREQUENCY*
  These inputs relate to the output frequency (number of GPS data steps) wanted in the graphic display and in the plot file (selecting 1 the graphical display will be automatically updated every 1/3 second for the previously specified input values).

A list of parameters available in the plot file is as follows:

TPLOT	Time in seconds from MAX ZULU START time
ZSP	Altitude in thousands of feet
CLIMB	Climb rate in hundreds of feet per minute
TAS	True airspeed in knots
VCAS	Indicated airspeed in knots (no wind)
HEAD	Magnetic heading in degrees
AS	Normal acceleration as felt by the pilot at the seat (1g for straight level flight)
ALOAD	Trajectory/Maneuver Gs (0g for straight and level flight)
AOA	Angle of attack in degrees
PITCH	Elevation angle of the aircraft longitudinal axis in degrees
YAW	Azimuth angle between the aircraft longitudinal axis and North in degrees
ROLL	Roll angle of transverse/wing axis about longitudinal axis in degrees
IFLAG	GPS data dropout flag (1-data, 0-no data)
TGT1	Closest threat target number (within $\pm 45^0$ ATA-Antenna Tracking Angle)
RNG1	Range to closest threat in nautical miles.
OT1	Off tail angle of closest threat in degrees
RNG2	Range to next closest threat in nautical miles.
OT2	Off tail angle of next closest threat in degrees

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviation	Definition	Unit
3D	three dimensional	---
2D	two dimensional	---
A/C	aircraft	---
ACM	air combat maneuvers	---
ACMI	air combat maneuvering instrumentation	---
ACT	air combat training	---
ACVAT	air combat visualization analysis tool	---
AFB	Air Force Base	---
AFFTC	Air Force Flight Test Center	---
AOA	angle of attack	deg
ASCII	American Standard Code for Information Interchange	---
ATA	antenna train angle	---
ATIS	airborne test instrumentation system	---
BFM	basic fighter maneuvers	---
BIT	built-in-test	---
BVR	beyond visual range	---
C	Celsius	---
C/A	coarse acquisition	---
CAS	control augmentation system	---
CRDA	Cooperative Research and Development Agreement	---
C_{LMax}	maximum lift coefficient	---
D	dimensional	---
DAS	data acquisition system	---
DC	direct current	---

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Continued)

Abbreviation	Definition	Unit
dB	decibels	---
dBm	decibel referenced to milliwatts	---
dBw	decibel, watts	---
deg	degree(s)	---
F	Fahrenheit	deg
FOV	field of view	---
FTE	flight test engineer	---
ft	feet	---
GPM	gallons per minute	---
GPS	global positioning system	---
g	acceleration due to gravity	32.2fps^2
gal	gallon	---
HUD	head-up display	---
Hz	hertz	cycles/sec
hr	hour	---
IRIG	Inter-Range Instrumentation Group	---
in	inch	---
JON	job order number	---
KCAS	knots calibrated airspeed	kt
KIAS	knots indicated airspeed	---
kt	knot(s)	---
LCD	liquid crystal display	---
lb	pounds(s)	---
MCX	miniature connector	---

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Continued)

Abbreviation	Definition	Unit
MET	mission elapsed time	---
MHz	megahertz	1,000 cycles/sec
m	meter	---
mA	milliamperes	---
min	minute(s)	---
mph	miles per hour	---
mV	millivolts	---
N/A	not applicable	---
NMEA	National Marine Electronics Association	---
NST	number of smoothing trials	---
N_2	core speed	---
n_y	lateral acceleration	---
n_z	load factor	---
n_x	axial acceleration	---
oz	ounce(s)	---
PA	pressure altitude	---
PC	personal computer	---
PFP	postflight processor	---
PLGR	portable lightweight GPS receiver	---
PPS	precision positioning system	---
p	roll rate	---
psia	pounds per square inch absolute	---
q	pitch rate	---
RMS	root mean square	---

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Continued)

Abbreviation	Definition	Unit
RTCM	Radio Technical Commission for Maritime	---
r	yaw rate	---
rpm	revolutions per minute	---
SACTS	Squadron Air Combat Training System	---
SCSI	small computer systems interface	---
SI	special instrumentation	---
SIT	smoothing interval of time	sec
SMA	subminiature adapter	---
S/N	serial number	---
sec	second(s)	---
T/W	thrust to weight	---
Temp	temperature	---
TPS	Test Pilot School	---
TR	technical report	---
USAF	United States Air Force	---
UTC	universal coordinated time	---
V_c	closure velocity	kt
VCR	videocassette recorder	---
V_t	true velocity	---
WVR	within visual range	---
α	angle of attack - true	---
α_{stall}	stall angle of attack	---
β	angle of sideslip - fine	---
θ	pitch angle	---

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Concluded)

Abbreviation	Definition	Unit
ψ	heading angle	---
ϕ	roll angle	---
μs	microseconds	---

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HEADQUARTERS 412TH TEST WING (AFMC)
EDWARDS AIR FORCE BASE, CALIFORNIA

MEMORANDUM FOR DTIC/OCC
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AFFTC/HO

FROM: 412 TW/TS - CSC (Technical Publications Office)

SUBJECT: AFFTC-TR-96-23, An Investigation of the Squadron Air Combat Training System (HAVE ACME)

To Whom It May Concern,

The attached Standard Form (SF) 298 had incorrect information in Block 8. It was brought to our attention and we have corrected the information and are sending you a copy per our distribution list. If you have any questions, please feel free to contact our office at (661) 275-9001. Thank you.

Ginny O'Brien
Ginny O'Brien
Technical Publications Department

Attachment:
SF-298

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DEPARTMENT OF THE AIR FORCE
HEADQUARTERS 412TH TEST WING (AFMC)
EDWARDS AIR FORCE BASE, CALIFORNIA

9 June 2003

MEMORANDUM FOR DEFENSE TECHNICAL INFORMATION CENTER
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FROM: AFFTC TECHNICAL LIBRARY
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SUBJECT: AFFTC TR 96-23

1. It has come to my attention that AFFTC TR 96-23, AN INVESTIGATION OF THE SQUADRON AIR COMBAT TRAINING SYSTEM (HAVE ACME) (ADA 310 490) has the wrong report number on the SF 298. Instead of AFFTC TLR 96-23, the report number should read AFFTC TR 96-23. All the other information is correct.

2. Your assistance in correcting the report number in the DTIC database would be greatly appreciated. If there are any questions, please do not hesitate to contact me at DSN 527-3606 or (661) 277-3606.

Jolaine Lamb
JOLAINE LAMB
AFFTC STINFO

Atch:
1. SF 298

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